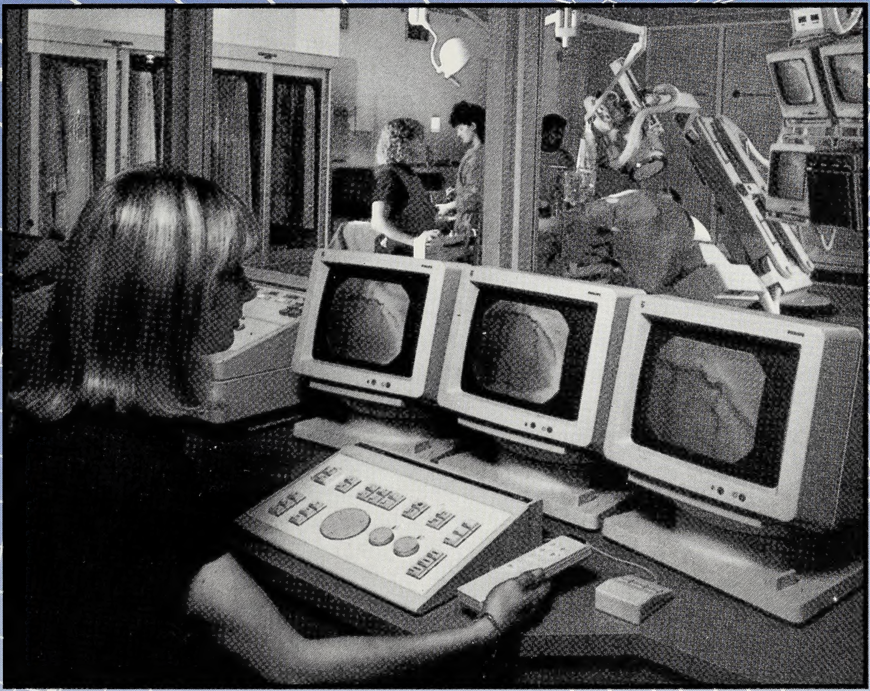
PHYSICS 30



Module 6

Electromagnetism

Distance Learning

Alberta EDUCATION

Physics 30

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Electromagnetism

Alberta
EDUCATION

Distance Learning

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Student Module
Module 6
Electromagnetism
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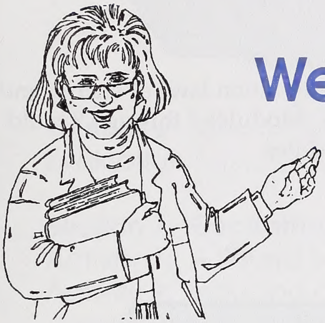
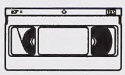


Welcome to Module 6!

We hope you'll enjoy your study of *Electromagnetism*.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

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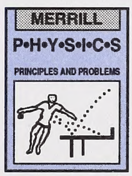
When you see this icon, study the appropriate pages in your textbook.



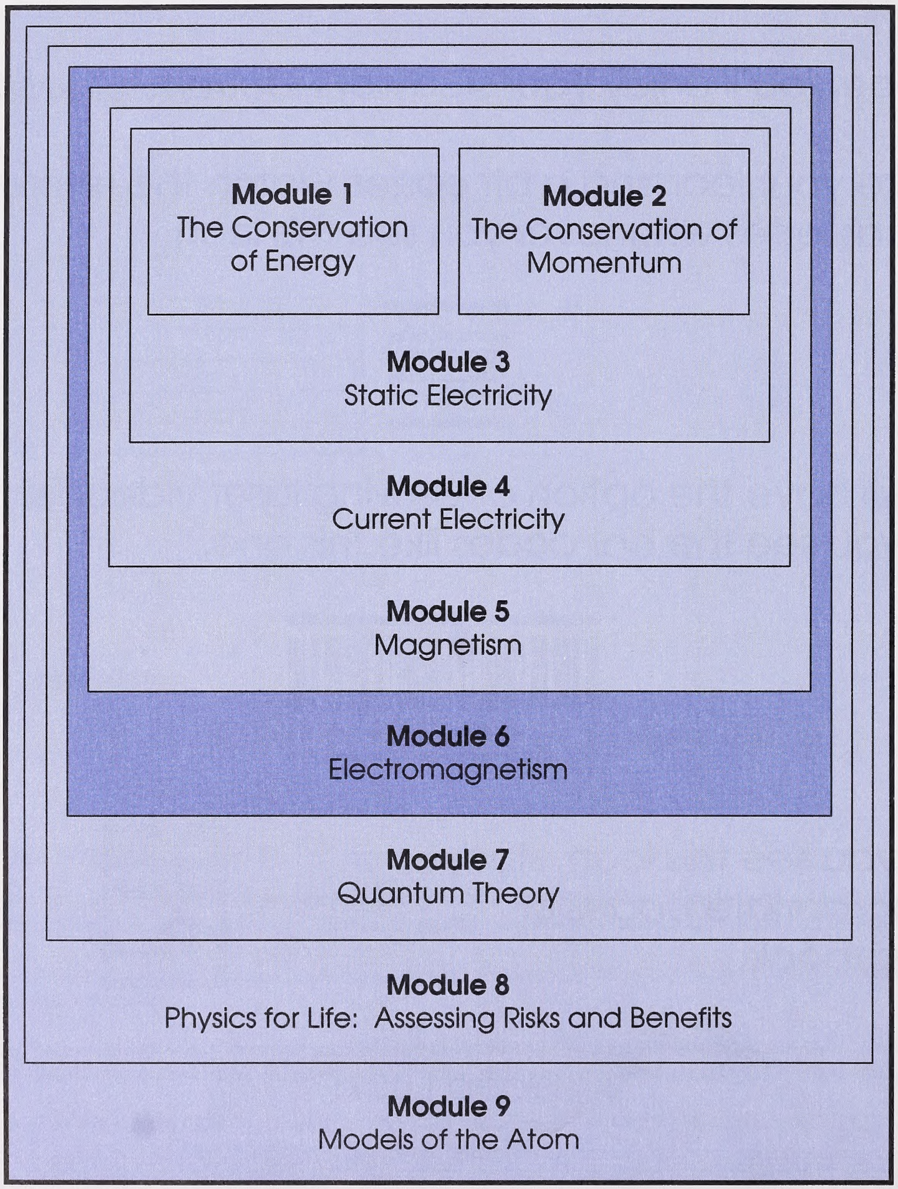
Good Luck!

Course Overview

This course contains nine modules. The first two modules develop the conservation laws of energy and momentum. The conservation of energy is at the heart of the entire course. Modules 3 through 9 build one upon the other and incorporate the main ideas from the preceding modules.

The module you are working in is highlighted in a darker colour.

PHYSICS 30



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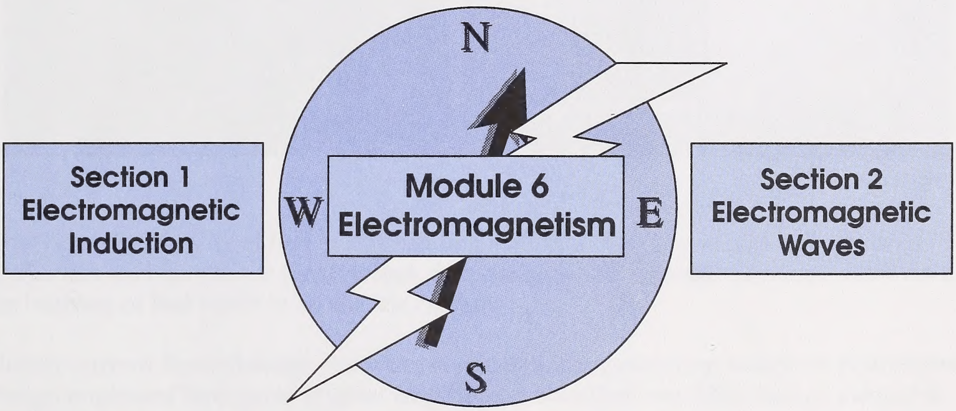
OVERVIEW

You are awakened from a restless sleep by the annoying buzz of your alarm clock. You roll over and reach to hit the snooze button for another ten minutes of tossing and turning. But wait – your alarm was set wrong and you have less than an hour to get ready! You quickly set the microwave oven to defrost a muffin for your breakfast while you grab a fast shower and blow-dry your hair. You grab your muffin and dash outside. You turn the key in the ignition of your car and are rewarded as the starter kicks in and the engine roars to life. As you pull out of the driveway, a glance at your digital watch assures you that you have just enough time.

Stop and consider how very different this scenario would have been just 100 years ago. How many of the devices that you use in your daily life are dependent on an electric power source? Microwave ovens, watches, automobiles, heating elements, radios, televisions – the list is endless! If you are like most people, you have probably not given much thought to just how dependent society is on such devices, or even how these devices work.

This module examines the principles behind electromagnetic induction and the nature and behaviour of electromagnetic radiation.



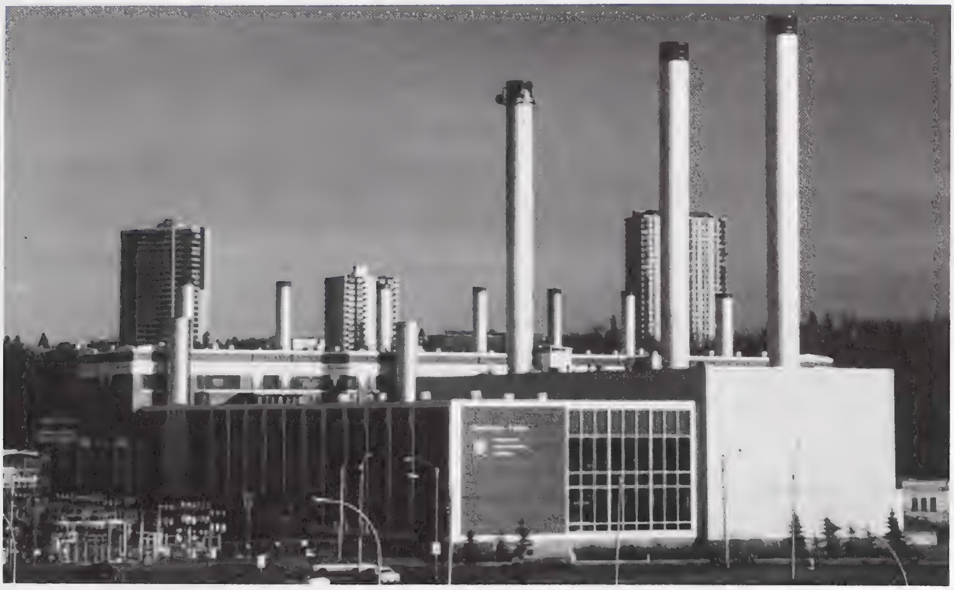
Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	60 marks
Section 2 Assignment	40 marks
TOTAL	**100 marks**

Section

1 Electromagnetic Induction



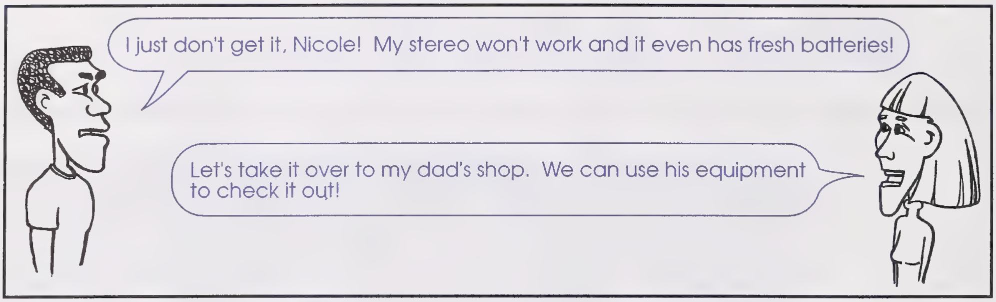
WESTFILE INC.

How does the burning of fuel at a generating station enable you to power household appliances such as electric fans, stereos, dishwashers, and vacuum cleaners? How does the burning of fuel result in an electric current?

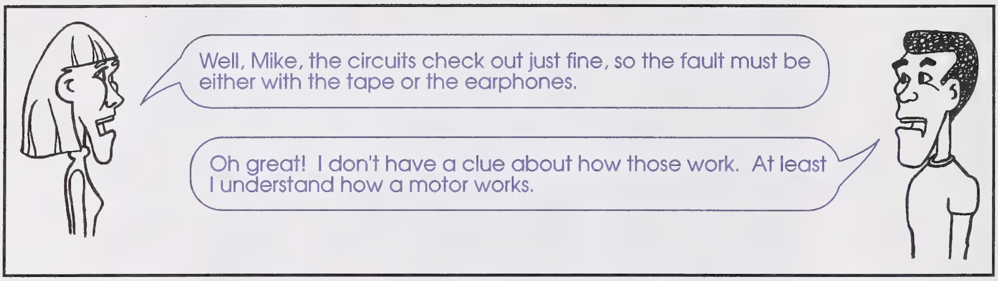
Electric current flows through the wires connecting the generating station to your home. Design engineers have gone to great lengths to ensure that very little electric current is actually transferred between the generating station and your home.

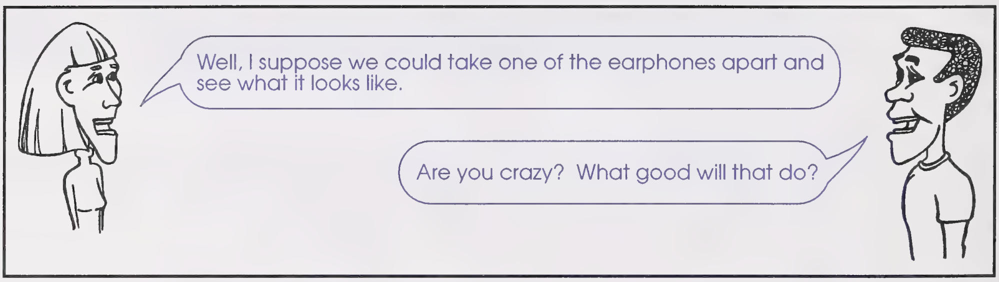
At the end of this section you should be able to combine what you learned in previous modules with the process of inducing a current to flow. You will apply the hand rules that you learned in Module 5 to the operation of devices like generators. By the end of Section 1 you should be able to relate the concepts that you have learned to the design of transformers.

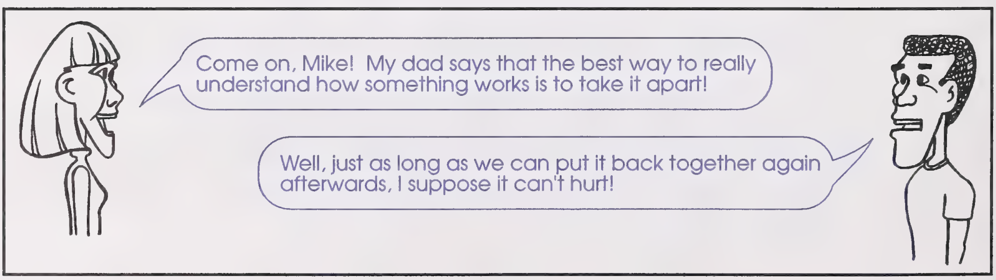
Activity 1: A Sound Solution



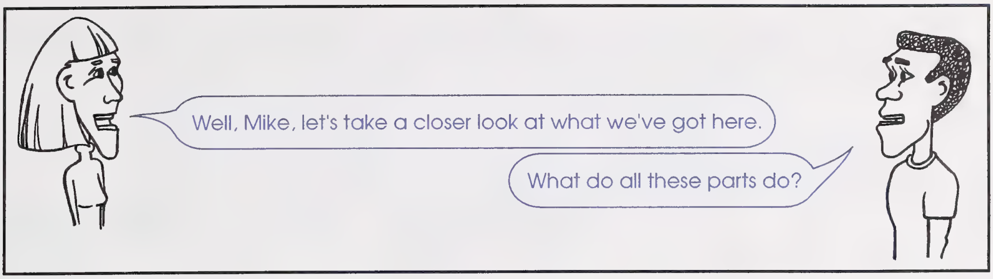
A little later on . . .

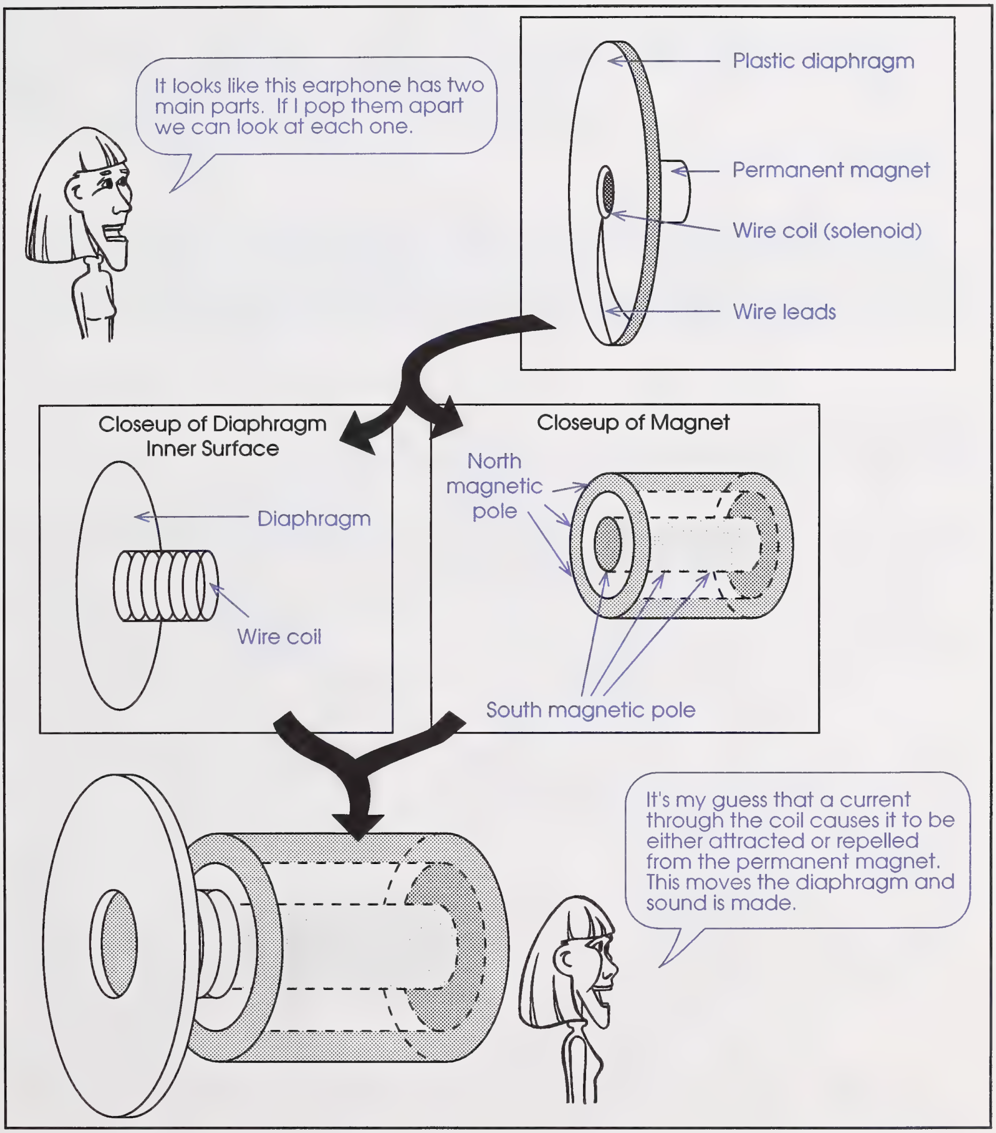




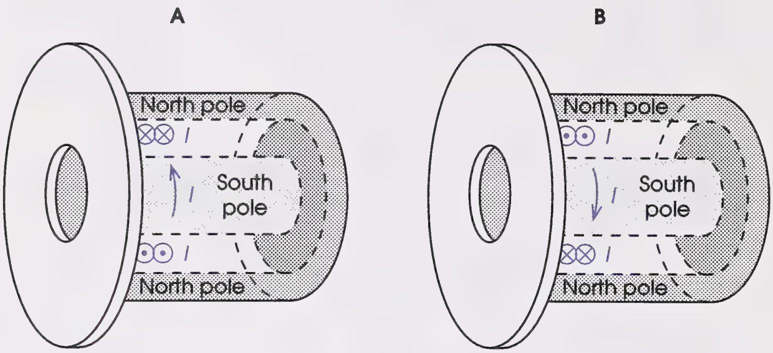


After a few tense moments, Nicole finishes taking apart the earphone and lays the pieces out on the tabletop.


Well, Mike, let's take a closer look at what we've got here.
What do all these parts do?


It looks like this earphone has two main parts. If I pop them apart we can look at each one.
Plastic diaphragm
Permanent magnet
Wire coil (solenoid)
Wire leads
Closeup of Diaphragm Inner Surface
Diaphragm
Wire coil
Closeup of Magnet
North magnetic pole
South magnetic pole
It's my guess that a current through the coil causes it to be either attracted or repelled from the permanent magnet. This moves the diaphragm and sound is made.

The following questions will allow you to expand on Nicole's idea of how the earphone works. Use the concepts that you learned in Module 5 and the following diagrams to answer these questions.

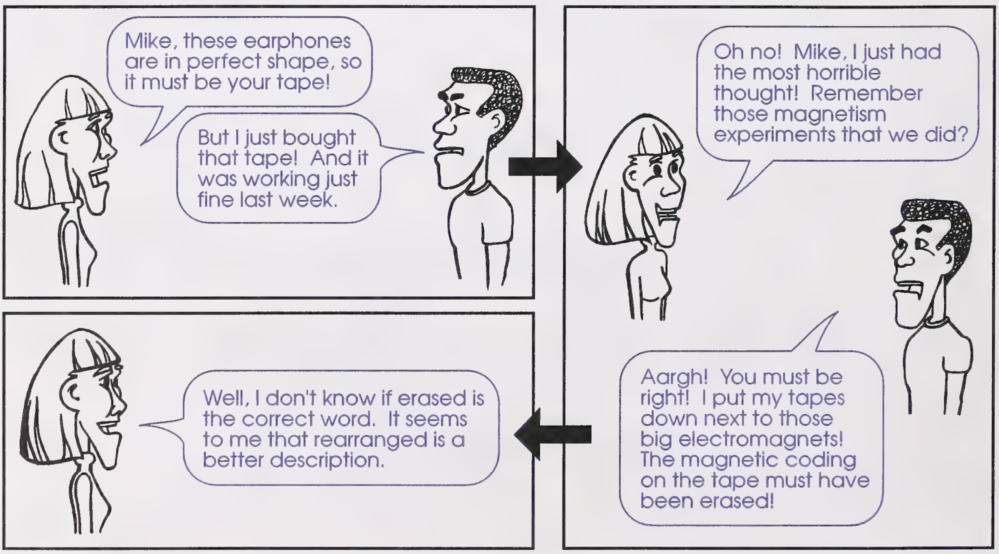


Note that the symbol *I* and the arrows refer to conventional current.

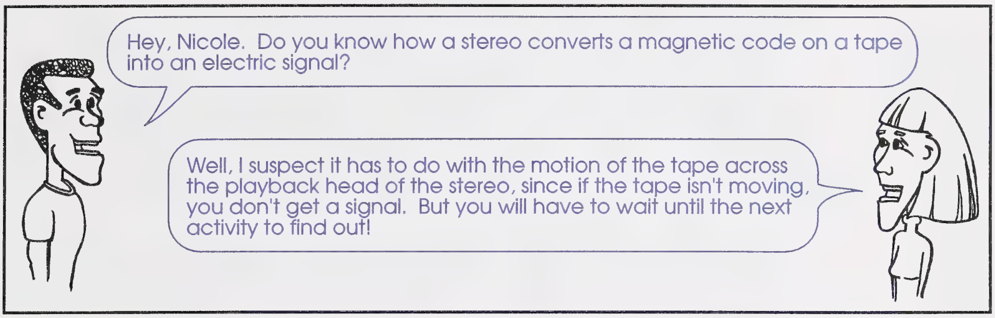
1. Refer to diagram A. Will the diaphragm be pulled towards the magnet or pushed out? Support your answer with the appropriate hand rule.

2. Refer to diagram B. Will the diaphragm be pulled towards the magnet or pushed out? Support your answer with the appropriate hand rule.

3. Imagine that the current in the coil begins flowing as shown in diagram A. The current then switches directions and flows as shown in diagram B. Finally, the current switches back and flows in the original direction. If this process repeats itself 250 times per second, describe the sound that would be produced.



4. Which term is more correct for describing the condition of Mike's tape in a physics sense, *erased* or *rearranged*? Use ideas from Module 5 to explain why you chose the answer that you did. You should note that the audiocassette is coated with a metal oxide.



Check your answers by turning to the Appendix, Section 1: Activity 1.

Activity 2: Inducing a Current

THE BETTMANN ARCHIVE

Michael Faraday was one of ten children in the family of a blacksmith. There was no education beyond reading and writing for children in working-class families at that time, so young Michael was made the apprentice to a bookbinder in 1805. He was 14 years old.

This proved to be very lucky for Faraday because he was exposed to books. His employer did not mind if he read the books and eventually allowed him to attend scientific lectures.

Faraday went on to become one of the greatest experimental scientists of all time. The picture shows Faraday announcing his discovery of electromagnetic induction to his wife on Christmas morning, 1821.

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

To discover the historical background of creating an electric current from changing magnetic fields, read the first three paragraphs on page 516 of your textbook. Be sure to refer to Figure 25-1 as you read.

1. Describe the basic condition that is essential in order for an electric current to be induced in a wire.

2. Explain why a conductor will cut more magnetic field lines if it moves perpendicular to the field than if it moves parallel to the field.

3. Who is credited with the discovery of electromagnetic induction?

electromotive force – the potential difference across the terminals of a source of electric energy when no current flows to the external circuit

The fact that current can be induced raises another question. In which direction does the induced current flow? To answer this question, read the last paragraph on page 516 and study Figure 25-2 on page 517 of your textbook. Recall from Module 5 that you should use the term *right-hand rule for force* instead of the textbook's phrase, *third right-hand rule*.

4. Explain why your thumb must point in the direction that the conductor is moving, while your palm indicates the direction of the induced conventional current. Does this contradict what you learned in Module 5?

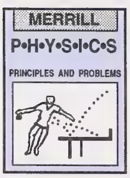
Check your answers by turning to the Appendix, Section 1: Activity 2.

EMF – abbreviation and preferred name for electromotive force

induced EMF – the source of the induced current created by electromagnetic induction

The current produced by the movement between a conductor and a magnet is called an induced current because the current is created even though the magnet never touches the conductor. If you think about it, you could also say that the circuit behaves as if there was an induced source of potential difference in the circuit since a current flows.

Traditionally, the term **electromotive force** has been used to describe the potential difference across the terminals of a source of electric energy when no current flows to the external circuit. Since it is a potential difference, and not a force measured in newtons, many people prefer to use the abbreviation **EMF**. In the case of electromagnetic induction, it is traditional to refer to the source of the induced current as the **induced EMF**.



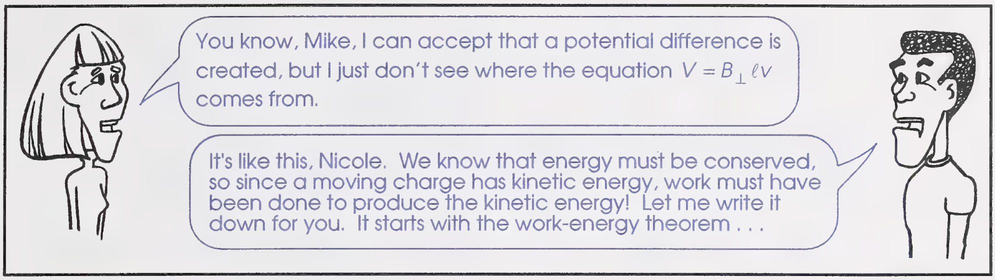
To find out more about the induced EMF, carefully read page 517 of your textbook.

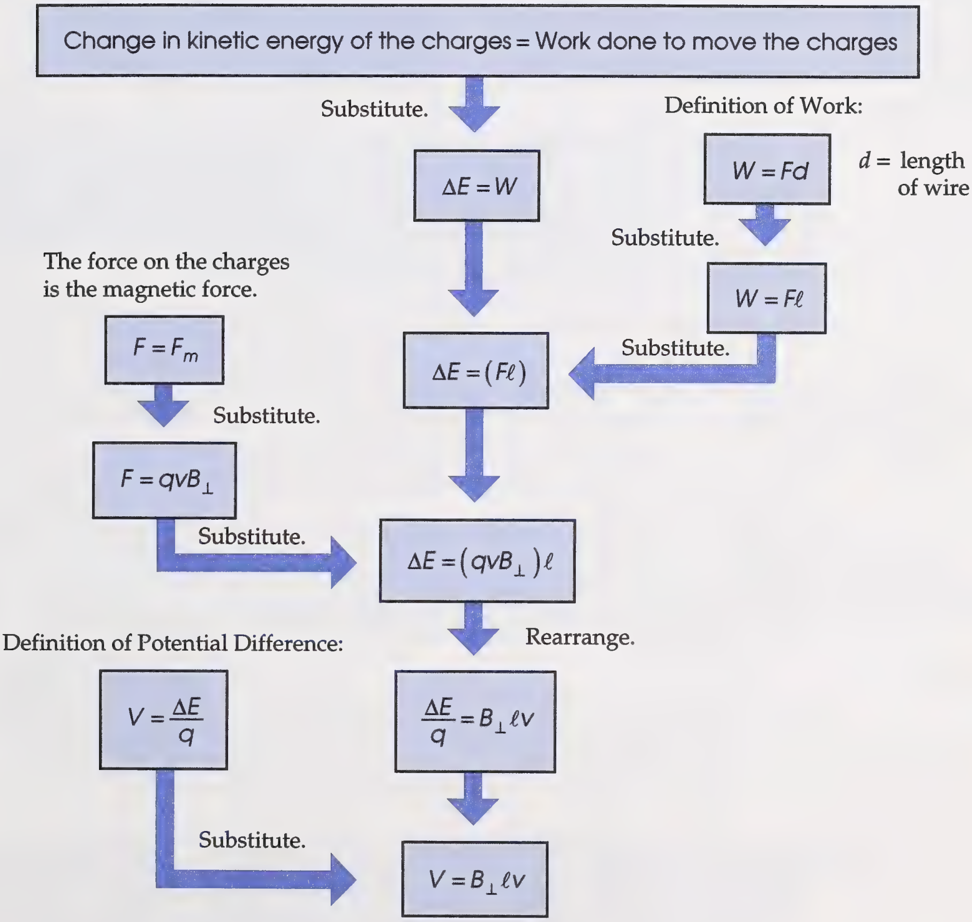
5. Write an equation for the induced EMF using the variables V, $B_{\perp}$, ℓ, and v. Since the induced EMF is actually a potential difference measured in volts, you should use the symbol V to represent it.

6. Why should you use the perpendicular subscript with the magnetic field variable?

7. Use a hand rule to explain why it is only the component of the velocity that is perpendicular to the magnetic field that generates an induced EMF.

8. Figure 25-3 on page 517 of your textbook shows the schematic diagram of a moving coil microphone. Suppose the diaphragm pushed the coil down towards the base of the magnets. Use a hand rule and a labelled diagram to explain the direction of the induced current through the coil.





This is the version of the equation for induced EMF that you should use for solving problems. Note the meaning of each of the variables.

Magnetic field strength. The perpendicular symbol reminds you that B is perpendicular to v and ℓ.

Induced EMF → $\boxed{V = B_{\perp} \ell v}$ ← Speed of the conductor

Length of the conductor

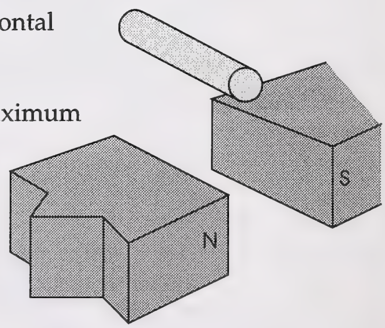
You can check your understanding of the equation $V = B_{\perp} \ell v$ by carefully studying the Example Problem found on page 518 of your textbook. Remember that electric current will only flow through a **complete** circuit and that you will be expected to use the version of the equation developed in this module.

9. Do Practice Problems 1 to 4 on page 518 of your textbook.

Check your answers by turning to pages 683 and 684 of your textbook.

You should have noticed that the questions from the textbook usually deal only with magnitudes; however, you are expected to be fluent with vectors and the hand rules. The following problem will allow you to combine several of these ideas to create a solution.

10. A 10.0-cm wire is held at rest 3.00 m above a horizontal 1.20-T magnetic field.



   a. When the wire is released, what will be the maximum induced EMF across the ends of the wire as it passes between the poles of the magnets?

   b. Determine which end of the wire will be positively charged and which end will be negatively charged.

Check your answers by turning to the Appendix, Section 1: Activity 2.

The other thing that you should be thinking about as you study this topic is the strong connection to what you have already studied. For example, you should now be able to appreciate why a microphone and an earphone are similar in design. They both act as devices which translate one form of energy into another form of energy.

11. Examine the following diagram. Complete the question by matching the words **microphone, earphone, generator**, and **motor** to the correct letter.

a. ________ effect

A coil of wire is forced to vibrate through a magnetic field.

b. ________ Converts sound waves into an electric current.

Converts an electric current into a mechanical vibration. c. ________

An electric current through a coil of wire placed in a magnetic field causes the coil to move.

d. ________ effect

12. Imagine that you are setting your tape recorder up to record an interview with a famous person. You notice that you accidentally packed your earphones instead of your microphone. Fortunately, you are still able to record the interview. Explain how this is possible using only the equipment mentioned.

Check your answers by turning to the Appendix, Section 1: Activity 2.

One of the most important applications of electromagnetic induction is the electric generator. To find out more about generators, read from the start of the last paragraph on page 518 to the bottom of the first paragraph on page 519 in your textbook.

13. Instead of a single piece of straight wire, the conducting wires are arranged differently in an electric generator. Describe this arrangement.

14. The armature of a generator consists of a cylindrical iron form or core with a radius of 2.7 cm with 500 turns of wire wrapped around it. Calculate the total length of wire on the armature.

The generator described in the textbook produces an induced current that changes direction as the armature rotates. Carefully read the second paragraph on page 519 of your textbook to discover the connection between the position of the armature and the direction of the induced current. Carefully study Figures 25-4 and 25-5 as you read.

15. Explain why the magnitude of the induced current is greatest when the loop is in the horizontal position.

16. Explain why the magnitude of the induced current is smallest when the loop is in the vertical position.

17. Refer to Figure 25-4(b). Explain why position 1 of the loop corresponds to a positive amplitude on the current graph, while position 3 corresponds to a negative amplitude.

18. Why should a graph of induced EMF versus time have the same shape as an induced current versus time graph?

Check your answers by turning to the Appendix, Section 1: Activity 2.

There are a number of similarities between the motors that you studied in Module 5 and the generators that you are learning about here. In this case, the generator is a source of alternating current, which is abbreviated to AC. Your work with electric circuits in Module 4 involved the current travelling in one direction, which is known as direct current, or DC. It is common to use the terms AC and DC in a way that ignores the fact that the C is an abbreviation for current. For example, you will read about AC voltage and AC current.

Read the first three paragraphs on page 520 in your textbook to gain further insight into these ideas.

19. Draw two flow charts, one to illustrate the operation of a motor and the other to illustrate the operation of a generator. The flow charts should be designed to stress similarities and differences.

20. If the AC current in North America has a frequency of 60 Hz, for how many seconds is the terminal for an AC generator positively charged? Your answer should include a calculation and a sketch of a graph.

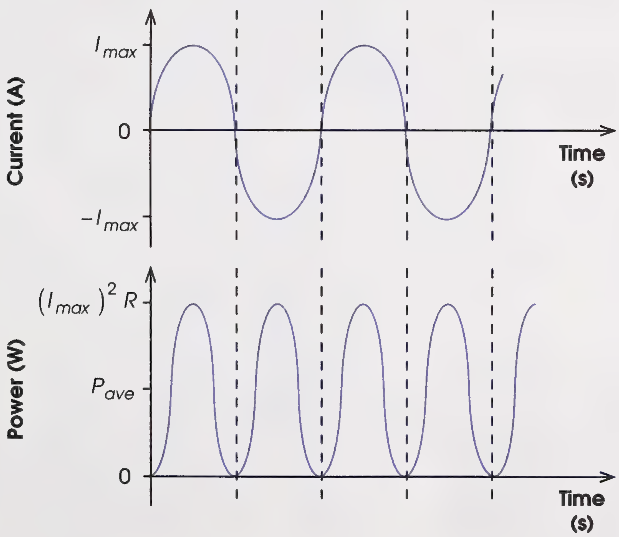
21. The textbook makes an error explaining why the light bulb in Figure 25-6 on page 520 in your textbook does not flicker. Use the idea that an incandescent light bulb works by heating the filament, according to $P = I^2 R$, to explain the error.

Check your answers by turning to the Appendix, Section 1: Activity 2.

As the graph of the instantaneous current produced by an AC generator shows, the current is positive for one-half of the cycle and negative for the other half. This shape of graph is called a sine wave. This means that the current alternates from going in one direction half of the time to going in the other direction the other half of the time. The average of all these current values taken over time would be zero since the sine wave graph is symmetrical.

However, as the question with the light bulb indicated, even though the average current flowing through a resistor might be zero, the average power would not be zero. Since the equation for this is $P = I^2 R$, the fact that the current value is squared means that the power always has a positive value. Thermal energy is created no matter which direction the charge flows in.

22. The following graphs show the values of current and power at the same instants of time.



a. What values of instantaneous current produce maximum values for instantaneous power?

b. What values of instantaneous current produce zero values for instantaneous power?

c. Refer to the lower graph to help explain why the average value for power can be calculated with the equation

$$P_{ave} = \frac{1}{2}(I_{max})^2 R.$$

23. Sketch two graphs to show the voltage and power produced by an AC generator at the same instants of time. Label the axes of both graphs in terms of V_{max}.

24. Explain why the average value for AC voltage is zero, while the average value for AC power is given by the equation $P_{ave} = \dfrac{\frac{1}{2}(V_{max})^2}{R}$.

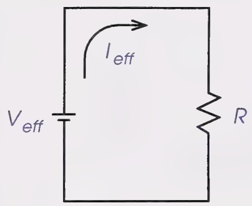
Check your answers by turning to the Appendix, Section 1: Activity 2.

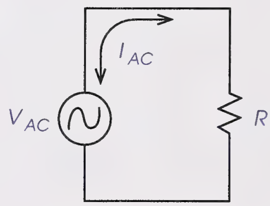
It is often necessary to calculate current and voltage values for AC circuits, but, as you can see, the values for AC current and voltage are continually changing. Which values would you use in calculations? Another problem is that all the equations that you developed in Module 4 to relate power, voltage, and current are based on DC circuits. Will they still be valid for AC circuits?

effective voltage – a DC voltage that would produce energy at the same rate as the AC source

effective current – a DC current that would produce energy at the same rate as the AC source

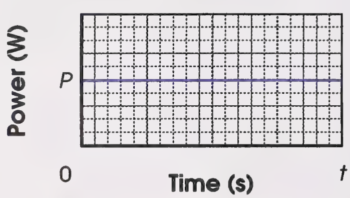
One solution to these problems is to represent an AC circuit with a DC circuit that uses energy at the same rate. For example, consider a single resistor circuit that converts electric energy into thermal energy. The AC voltage is represented by an **effective voltage** and the AC current is represented by an **effective current**. These values are called *effective* because they have the same effect from an energy point of view and because they can effectively represent the range of values in the corresponding AC circuit.



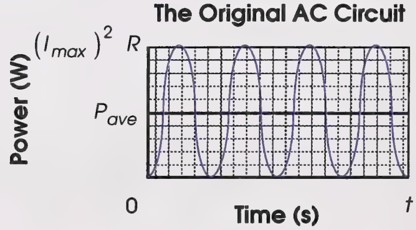


(∿) refers to an alternating current generator.

The Effective DC Circuit



The Original AC Circuit



25. If you had only the graphs to refer to, explain how you would calculate the thermal energy produced by the DC circuit in the time interval from 0 to t.

26. Imagine that you have a pair of scissors and that you are allowed to cut up the graph for the AC circuit.

    a. Explain how you would cut the AC graph to show that it encloses the same area as the DC graph.

    b. The thermal energy produced by the AC circuit can be calculated by using the equation $E = \frac{1}{2}(I_{max})^2 Rt$. Use your answer from question 27. a. to explain the origins of the equation.

The definitions for effective voltage and effective current are based on the idea that the effective DC circuit uses energy at the same rate as the original AC circuit. This idea can be used to derive an equation that relates the effective value for current to the maximum value of current in the AC circuit. This is shown in the following flow chart that corresponds to the circuits and graphs shown on the previous page.

$$E_{DC} = E_{AC}$$

$$Pt = P_{ave}t$$

$$(I_{eff})^2 Rt = \frac{1}{2}(I_{max})^2 Rt$$

Average or mean of the AC current squared

$$(I_{eff})^2 = \boxed{\frac{1}{2}(I_{max})^2}$$

Square root of the mean AC current squared (root-mean-square)

$$I_{eff} = \boxed{\sqrt{\frac{1}{2}(I_{max})^2}}$$

$$I_{eff} = \frac{1}{\sqrt{2}} I_{max}$$

$$I_{eff} = (0.7071) I_{max}$$

27. Explain why the effective value for AC current is sometimes called the root-mean-square, or rms, value.

28. Using the derivation for effective current as a guide, show the derivation of the equation for effective voltage: $V_{eff} = (0.7071)V_{max}$.

29. Do Concept Review question 1.4 on page 523 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 2.

It is the effective values for current and voltage that are usually specified or measured. This is because these values can be used to calculate the average AC power. For example, the 120 V available from a standard wall outlet is actually 120 V rms, not the maximum AC voltage provided by the outlet.

Study the Example Problem on page 521 of your textbook. Note that only the effective values for voltage and current can be substituted in Ohm's law.

30. Do Practice Problems 5 through 8 on page 521 of your textbook.

Check your answers by turning to page 684 of your textbook.

In this activity you have seen how an electric generator creates AC power. You have also seen that effective values for AC current and voltage must be used in calculations. It's fascinating that all of this stems from the idea that when a conductor cuts magnetic field lines, a current is induced in that conductor. In the next activity you will discover that there is another way to state this principle that sheds light on even more applications.

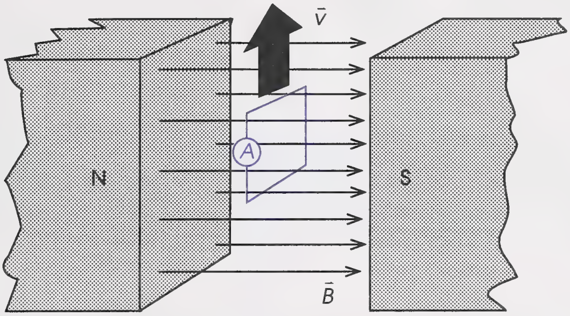
Activity 3: Lenz's Law

In the last activity you were introduced to the concept of electromagnetic induction. The whole concept was based on what happened when a length of straight wire cut through magnetic field lines. Although this is a useful place to begin, most applications involve loops and coils of wire rather than straight wires. In this activity you will learn to look at electromagnetic induction in a new way that is better suited to loops and coils.

This new point of view will be developed by presenting a series of experiments that represent some of the early work done by experimenters like Michael Faraday and Joseph Henry. As you read through the description of each experiment, be sure to examine the accompanying diagram.

Experiment 1:

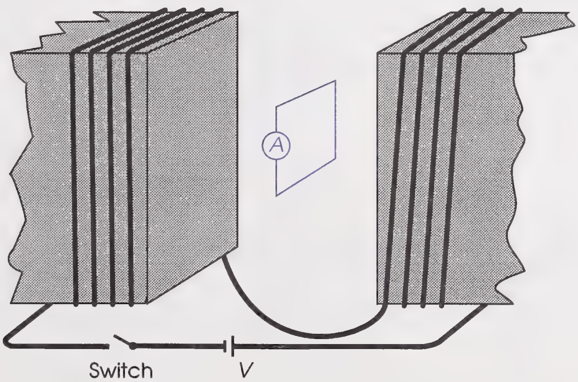
A very small loop of wire that includes a tiny ammeter is pulled up through a uniform magnetic field. No induced current would be indicated as long as the loop stayed within the region of the uniform field. However, when the loop passes near the edge of the field, the number of field lines passing through the loop changes. A current is then induced.



This experiment suggests that it's not really the motion of the loop through the uniform magnetic field that induces the current. A current is induced when the number of field lines through the loop changes. The next experiment will test this idea further.

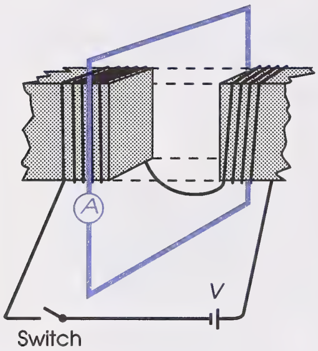
Experiment 2:

In this experiment the very small loop of wire with the ammeter is not moved at all. As the switch is closed, the electromagnets suddenly create magnetic field lines. A current is momentarily induced. Once the magnetic field is established and remains uniform, the induced current stops. When the switch is opened, the magnetic field lines are reduced to zero. At this instant a current is induced, but this time it flows in the opposite direction. Once the magnetic field has completely disappeared, the induced current stops.



This experiment seems to verify that the number of field lines passing through the loop must change in order for a current to be induced.

Experiment 3:



In this experiment a much larger loop and ammeter that completely enclose a much smaller set of electromagnets are used. The outer loop is so much larger that the magnetic field of the electromagnet is much weaker in the region occupied by the wire loop.

As in the previous experiment, a current is induced only when the switch is opened and closed. Since the wire that makes up the outer loop is so far away from the changing magnetic field lines, it cannot be the interaction between this wire conductor and the magnetic field lines that induces the current. This suggests that the induced current must be due solely to the changing number of electric field lines which are induced by the changing magnetic field. The wire of the outer loop simply provides the charges to produce the induced current.

1. Identify the basic cause of the induced current in the loop suggested by these three experiments.

Check your answer by turning to the Appendix, Section 1: Activity 3.

magnetic flux – the product of the perpendicular component of the magnetic field and the area of a loop of wire

These experiments indicate that in order for a current to be induced in a loop of wire, the total number of magnetic field lines passing through the loop must change. A more convenient way to say "total number of magnetic field lines passing through a loop" is to use the term **magnetic flux**. The magnetic flux can be described by the following equation.

$$\text{Magnetic flux} \rightarrow \boxed{\Phi_B = B_\perp A} \leftarrow \text{Area of the loop}$$

Magnitude of the magnetic field that acts perpendicularly to the area of the loop

2. Use the equation to determine how the units of flux can be expressed in terms of teslas and metres.

3. A circular loop of wire has a diameter of 5.2 cm. A uniform magnetic field of 2.1×10^{-3} T acts perpendicularly to the area of this loop. Calculate the magnetic flux through the loop.

4. The loop of wire in the previous question is bent into a rectangular shape with sides 6.0 cm and 2.17 cm long. If the magnetic field remained the same, what is the magnetic flux through this rectangular loop?

5. The rectangular loop of wire in the previous question is moved to a new location where the magnetic field passing through the loop is only 8.5×10^{-4} T. Calculate the magnetic flux through the loop in this case.

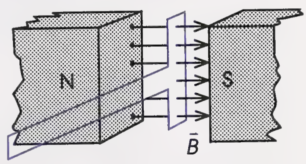
6. Refer to your answers to the previous three questions. Identify two ways to change the magnetic flux through a loop of wire.

Check your answers by turning to the Appendix, Section 1: Activity 3.

If you now reconsider experiments 1 through 3 that were presented earlier in this activity, the results can be explained in terms of magnetic flux.

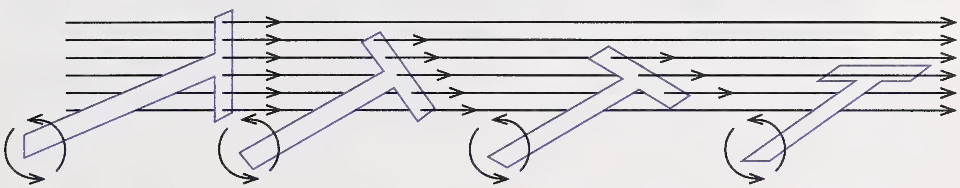
A current is induced in a loop when the magnetic flux through that loop changes.

The simple generator that you studied earlier can now be reinterpreted in terms of magnetic flux. Remember that the magnetic flux is proportional to the total number of magnetic field lines that pass through the loop. When the loop is in the vertical position, the flux could be indicated by a total of six field lines passing through the loop.



However, when the loop begins to rotate, the total number of magnetic field lines passing through the loop changes. As the loop rotates through one-quarter of a cycle, the magnetic flux decreases to zero, as shown in the following simplified diagram.

Time:	0	1 ms	2 ms	3 ms
Number of Field Lines :	6	5	3	0



7. The loop is not changing shape and the magnetic field is uniform. Explain why the magnetic flux through the loop is changing.

8. Between which two times is the change in the magnetic flux the smallest?

9. Based on your answer to the previous question, when would you expect the induced current to be the smallest?

10. Are your answers to the previous two questions consistent with Figures 25-4 and 25-5 on page 519 of your textbook? Explain.

11. Between which two times is the change in the magnetic flux the largest?

12. Based on your answer to the previous question, when would you expect the induced current to be the largest?

13. Are your answers to the previous two questions consistent with Figures 25-4 and 25-5 on page 519 of your textbook? Explain.

14. Calculate the period of rotation and frequency for this generator. What is the frequency of the AC current produced by this generator?

Check your answers by turning to the Appendix, Section 1: Activity 3.

The idea of magnetic flux is very helpful for predicting the conditions necessary for a current to be induced in a loop of wire. The only question that remains is the direction of the induced current through the loop. There should be a way to predict this as well.

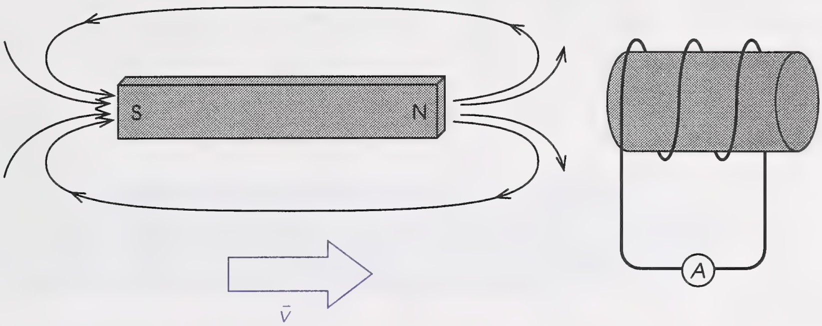
Read from page 523 to the bottom of the first paragraph on page 524 in your textbook. Take careful note of Figure 25-7 and remember that your textbook calls the right-hand rule for coils "the second right-hand rule."

15. State Lenz's law.

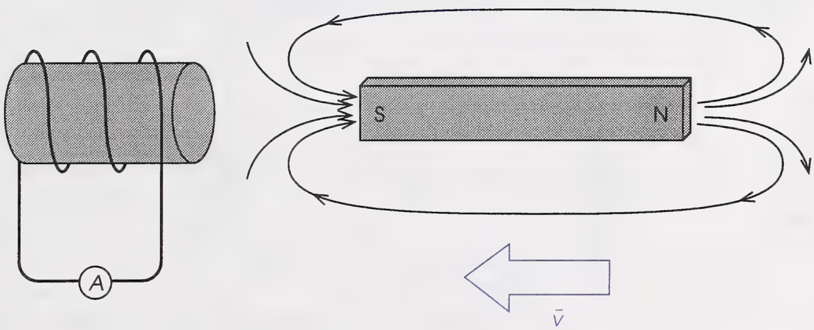
To apply Lenz's law you must first determine whether the magnetic flux that induced the current is increasing or decreasing. Then choose the magnetic field direction that opposes this change. The final step is to apply the appropriate hand rule for coils to determine the direction of charge flow within the coil. Use your right hand for conventional current and your left hand for electron flow.

16. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by indicating the direction of the induced magnetic field lines and the direction of the induced conventional current.

a.

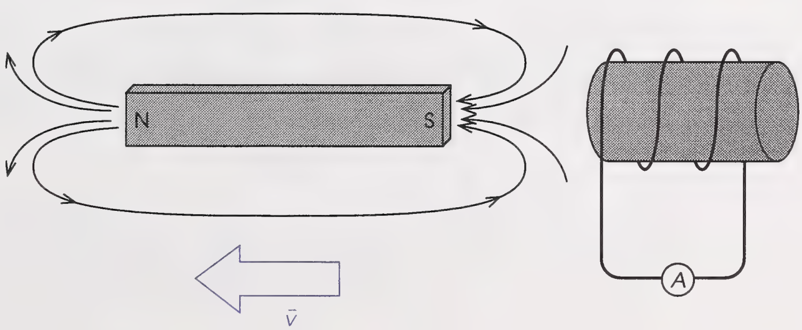


b.

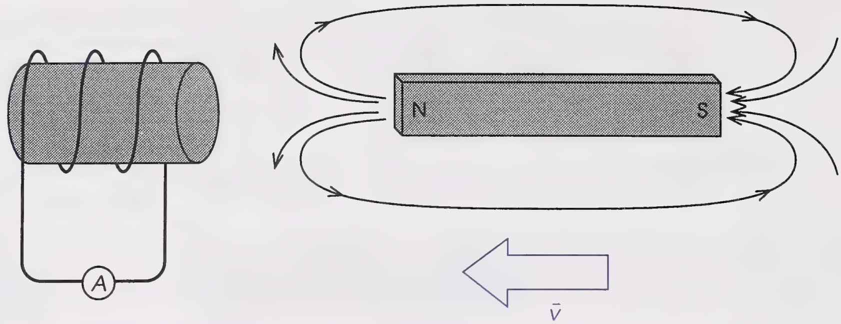


17. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by indicating the direction of the induced magnetic field lines and the direction of the induced electron flow.

a.

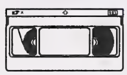


b.



Check your answers by turning to the Appendix, Section 1: Activity 3.

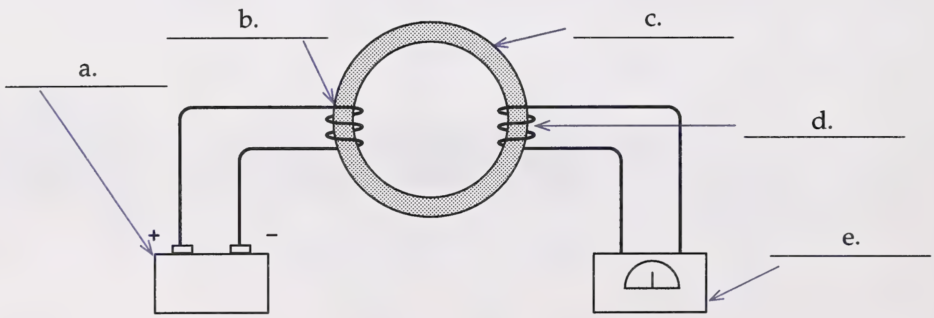
If you had trouble applying Lenz's law in the previous two questions, you may need to work step-by-step through some more examples.



The video series *Electromagnetism* contains a ten-minute program called *Electromagnetic Induction*. Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

It is very important that you understand how to use the hand rule for coils if you are going to apply Lenz's law, so be sure to put your hand up close to the TV screen and practise the hand rule as you watch the tape. The other thing to keep in mind is that this program uses the word *current* to refer to electron flow, so be sure to use your left hand.

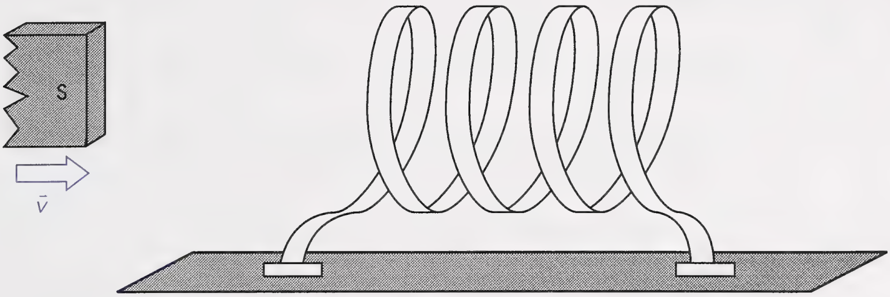
18. Michael Faraday is credited with the discovery of electromagnetic induction. Complete the question by providing the correct name for each part.



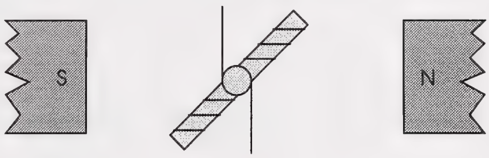
19. What is the name given to the device shown in the previous diagram?

20. State Lenz's law as given in the video.

21. The following diagram represents Lenz's law in the diagram form shown in the video. Copy the diagram into your notebook and complete the diagram by indicating the magnetic polarity of the coil, the induced electron flow, and the magnetic field lines that surround the coil. Remember to use your left hand!



22. Refer to this diagram as you answer these questions.



   a. What did this diagram represent in the video?

   b. What is the name for the rotating part between the poles of the magnet?

   c. What happens as you turn the rotating part? Explain your answer.

Stop the videocassette at the end of the program.

Check your answers by turning to the Appendix, Section 1: Activity 3.

The exploration of Lenz's law up to this point has been a discussion of ideas through diagrams, explanations, and video programs. In the next investigation you will have an opportunity to experience Lenz's law firsthand.

Investigation: The Lenz's Law Swing

Science Skills

- ❒ A. Initiating
- ❒ B. Collecting
- ❒ C. Organizing
- ☑ D. Analysing
- ❒ E. Synthesizing
- ❒ F. Evaluating

Purpose

In this investigation you will complete a demonstration and then you will use Lenz's law to analyse your observations.

Materials

You will need the following materials for this investigation:

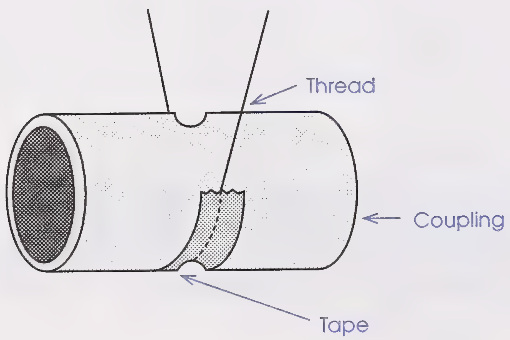
- 2 m of thread
- a bar magnet or a cylindrical magnet
- 30 cm of masking tape
- a $1\frac{1}{2}$-inch copper coupling

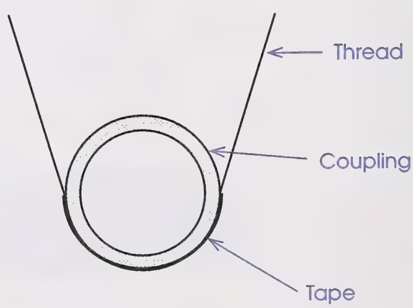
Pre-lab Analysis

23. Should the copper coupling be attracted to the bar magnet? Verify your answer using the coupling and the bar magnet.

Procedure

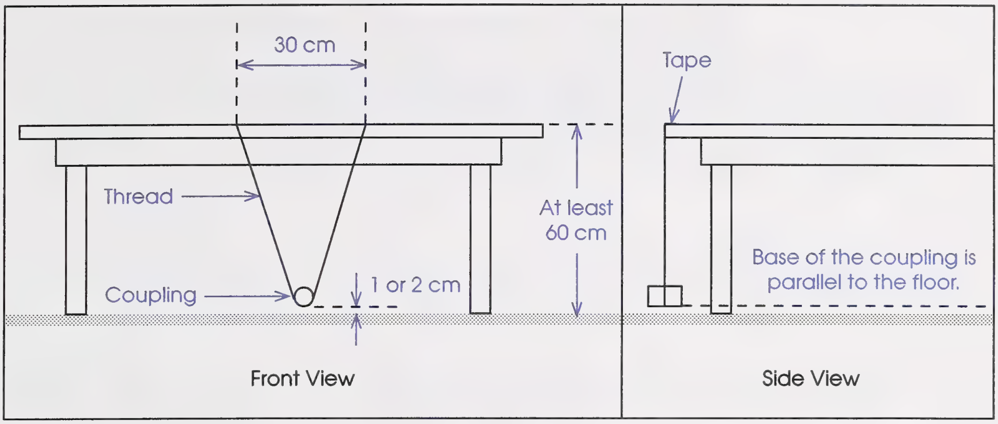
- Read through this entire procedure before starting this investigation.
- Tape the middle of the length of thread to the copper coupling as shown in the following sketches.



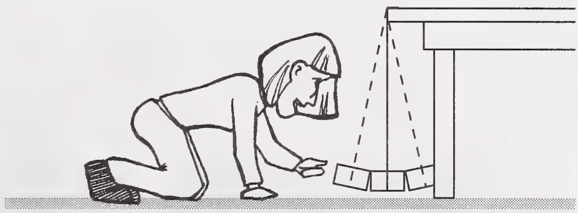


Note that the thread is taped to the groove in the coupling and that the tape only goes half way around the coupling. When done properly the coupling should hang from the thread as shown.

- Attach the ends of the thread to the top of a table with the tape. The following diagrams show the proper arrangement of the materials.

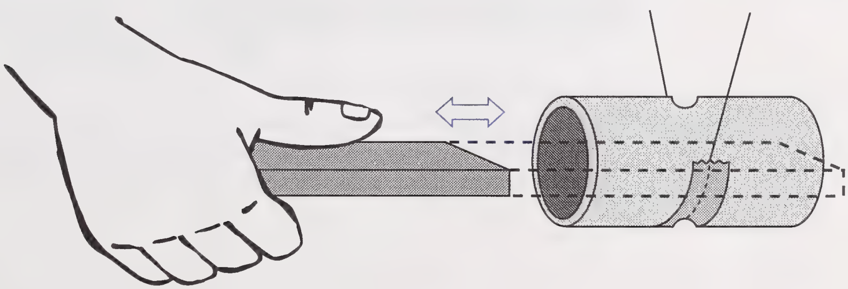


- The coupling should now be able to move freely back and forth like a swing. Gently pull the coupling back and set it swinging so that it has an amplitude of about 10 cm. Observe the motion of the coupling while you get a sense of the natural rate of vibration of the swinging coupling.



- Stop the coupling from swinging and wait until the vibrations completely stop.

- Hold the bar magnet in your hand and align it so that when you move your hand back and forth along the floor, the bar magnet can pass **through** the hanging coupling without touching it. You may find that a cylindrical magnet works better.



- Begin to move the magnet back and forth through the centre of the coupling by sliding your hand back and forth along the floor. Try to keep this back and forth motion at the natural frequency of the coupling. You can tell if you are doing it right because the coupling will start swinging. Stay in time with the swinging coupling as if you were pushing someone on a swing. If you do this well, you can get the coupling to swing with an amplitude of nearly 10 cm.

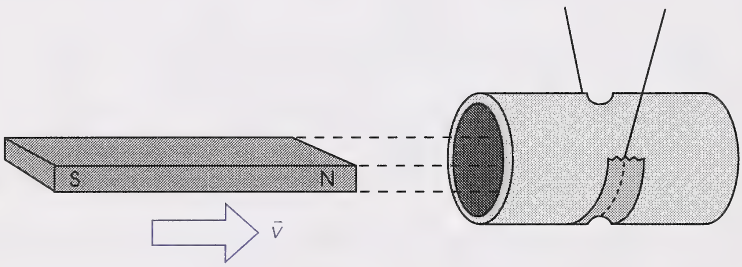
- Repeat the experiment using a nonmagnetic object such as a pencil or screwdriver instead of the bar magnet.

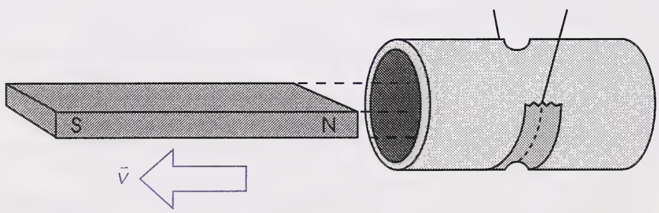
24. Does the coupling swing when the bar magnet is substituted with a nonmagnetic object?

Analysis

25. Copper is not a ferromagnetic material, yet the copper coupling seems to follow the motion of the magnet. What principle must be at work here?

26. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams in your notebook by labelling the induced current and the induced magnetic field lines around the coupling. Also write a brief step-by-step explanation of how magnetic field lines are induced around the coupling.





27. Look up the definition of the word *resonance* from your work in Physics 20. Explain how you used the idea of resonance to cause the coupling to swing.

Conclusions

28. How can you be sure that the swing of the coupling was caused by Lenz's law, not by air currents created by moving your hand back and forth?

Check your answers by turning to the Appendix, Section 1: Activity 3.

Activity 4: Applications

You may be quite surprised to learn that Lenz's law actually has significant impact on your life. In some cases the applications are interesting curiosities, while others touch much of the technology that you use on a daily basis.

In this activity you will have an opportunity to practise the concepts that govern electromagnetic induction as you sample a number of applications.

Back-EMF

The armature of a motor is set in motion by causing a current to flow through its coils. Since the coils are arranged within a strong magnetic field, a magnetic force acts on these current-carrying coils, causing the armature to turn. This idea, known as the motor principle, was studied in Module 5. However, Lenz's law requires that the explanation be modified to include an additional effect.

When the armature is set into motion, its coils are forced to rotate so that the total number of magnetic field lines through these coils is continually changing. In other words, the changing magnetic flux through the coils induces a current to flow. The motor cannot help but be a generator at the same time as it operates as a motor. Lenz's law predicts that this induced current will **oppose** the motion of the armature. That is, an induced current will oppose the original current through the coils. The net effect is that the net current through the coils is reduced. It is as if an additional source of EMF, called the back-EMF, was working to reduce the current by opposing the input voltage supplied to the motor.

back-EMF – the induced EMF in a motor that acts to oppose the motion of the motor

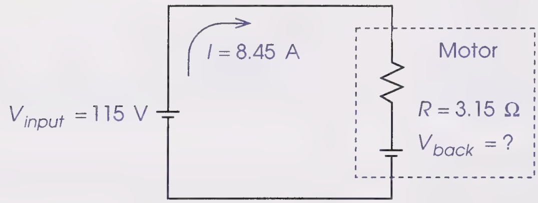
The interesting part of all of this is that the faster the motor turns, the greater the change in the magnetic flux through the coils, and the greater the opposing current and back-EMF. The following example problem will help to illustrate the process of creating a back-EMF.

Example

A motor has an armature wound with a length of copper wire. The total resistance of this wire is $3.15\ \Omega$. This motor draws 8.45 A when running at full speed and connected to a 115-V DC source. Calculate the back-EMF.

Solution

- Draw a schematic diagram which illustrates the data.



Note that the back-EMF is shown to oppose the input voltage.

- Apply Kirchhoff's loop rule to the circuit.

$$\begin{aligned} V_{input} - V_{resistance} - V_{back} &= 0 \\ V_{input} - IR - V_{back} &= 0 \\ V_{back} &= V_{input} - IR \\ &= (115\ \text{V}) - (8.45\ \text{A})(3.15\ \Omega) \\ &= (115\ \text{V}) - (26.62\ \text{V}) \\ &= 88\ \text{V} \end{aligned}$$

The negative signs indicate that there is a voltage drop (loss of electric energy) across the resistor and the back-EMF.

This example illustrates the fact that the back-EMF is usually a substantial amount of voltage. If the motor had no load at all, the speed of the armature would increase until the back-EMF actually equalled the input voltage. However, as the following questions will illustrate, the load connected to the motor tends to slow it down and therefore reduce the back-EMF. Be sure to refer back to the example as you solve these questions.

1. A large DC motor has an armature that has an effective resistance of $4.8\ \Omega$. The motor is connected to a DC source of 115 V.

   a. When the motor turns at full speed, the back-EMF is 103 V. Calculate the current drawn by the motor. Be sure to begin your solution with a schematic diagram.

   b. Suppose the motor was connected to a more powerful load that forced it to turn at half speed. Calculate the current that would be drawn by the motor in this case. Be sure to begin your solution with a schematic diagram.

   c. Now imagine the same motor to be overloaded to the point that it stops in the middle of its operation. Calculate the current that would be drawn by the motor in this case. Be sure to begin your solution with a schematic diagram.

2. The answers to the previous questions indicate that as the load connected to the motor is increased, more current is drawn from the source of input voltage. Use a conservation law to explain why this makes sense.

3. Under what conditions could a motor have the full input voltage applied to it and yet have no back-EMF created?

4. Refer to your answer to the previous question to explain why motors draw large currents when they first start and why they can burn out if they are forced to stop turning in the middle of their operation.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

To find out more about back-EMF and how this idea can be interpreted in a slightly different way, read the third, fourth, and fifth paragraphs on page 524 and the last two paragraphs on page 525 of your textbook.

5. Why will lights dim when a machine with a large electric motor is first switched on? Assume that the lights are on the same circuit as the machine.

6. What is self-inductance?

7. If a car is at rest, it takes a large force for a person to push it and get it going. Once the car is in motion, anyone pushing it may have considerable difficulty stopping it. Explain the similarities between this situation and the effect known as self-inductance.

Check your answers by turning to the Appendix, Section 1: Activity 4.

The Transformer

transformer – a device for increasing or decreasing AC voltage

There is an electromagnetic equivalent of the mechanical lever – the **transformer**. You have seen how a basic transformer is set up and the physics behind its operation, but rather than just read or watch an explanation, it's better to discover it yourself. You will be using the solenoids that you made in Module 5 in this investigation.

Investigation: Induction and the Transformer

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will confirm that magnetic fields are capable of inducing electric currents, and that a transformer will actually allow induction between two unconnected coils.

Materials

You will need the following materials for this investigation:

- both a 400- and 800-turn solenoid (from Module 5)
- four wire leads with alligator clips at both ends
- a multimeter capable of measuring microamperes, or a microammeter
- a cylindrical magnet
- a variable power supply (3-V and 9-V output)
- a large steel bolt $\left(\frac{1}{2}\text{-inch diameter, 4 inches long}\right)$
- 30-Ω power resistor rated at 5 W

Caution

Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.

- Only replace the fuse inside the meter with the specified or approved equivalent fuse.

- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.

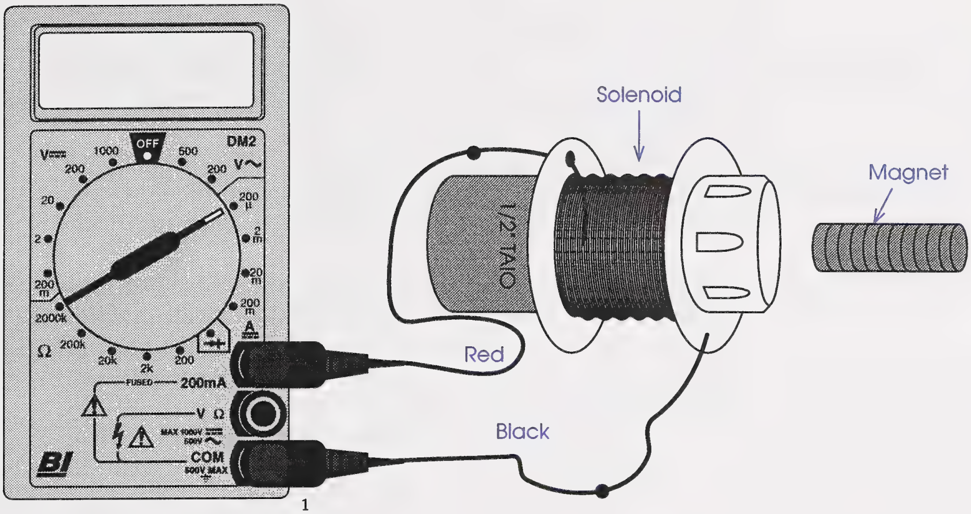
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure and Observations

- You will be using the 400-turn solenoid for this part of the investigation.

- Arrange the apparatus as shown in the diagram at the top of the following page. Be sure to set the multimeter to the microampere setting.



[1]

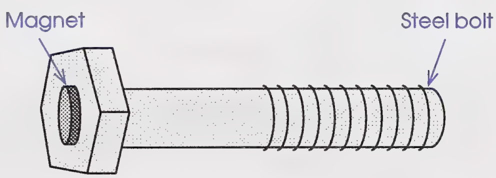
- Push the magnet into the solenoid and note the change on the display of the multimeter. Rapidly withdraw the magnet from the solenoid and note the change on the display of the multimeter.

- Repeat the previous steps using the 800-turn solenoid. Try to move the magnet towards the solenoid at the same speed as in the first trial.

8. a. What change was observed on the display of the multimeter between the times when the magnet approached the solenoid and the magnet was withdrawn from the solenoid?

   b. What change was observed on the display of the multimeter between the times when the 800-turn solenoid was used and the 400-turn solenoid was used?

- Remove one of the magnets from the bar and place it on the end of the large steel bolt, as shown in the following diagram.



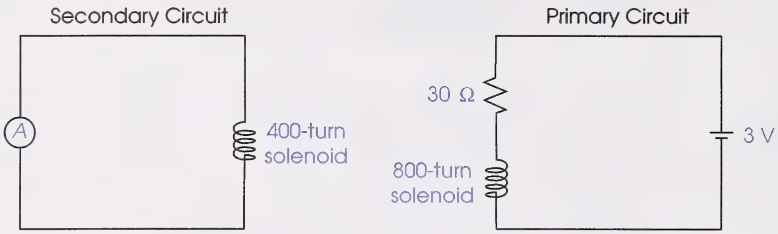
[1] Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

- Push the steel bolt into the solenoid at about the same speed that you used for the magnet. Note the change on the display of the multimeter.

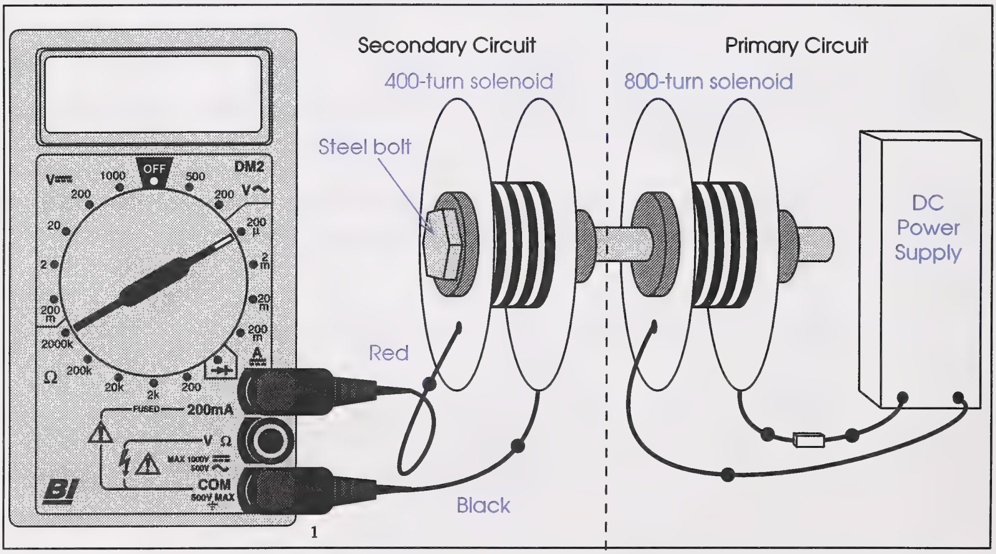
9. Which produces a stronger magnetic field, the bar magnet or the steel bolt? Explain your answer in terms of domain theory.

10. Are your observations for the bar magnet and the steel bolt consistent with your answer to the previous question? Explain your answer.

- Construct two separate circuits. One circuit, called the primary circuit, consists of the 30-Ω power resistor in series with the 800-turn solenoid and a DC power supply set at 3 V. The power supply should **not** be turned on. The other circuit, called the secondary circuit, consists of the 400-turn solenoid in series with the microammeter.



- Place the steel bolt through both solenoids, as shown in the following diagram.



[1] Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

- Turn on the DC power supply.
- While watching the display on the microammeter, disconnect the positive lead from the power source.
- While watching the display on the multimeter, reconnect the positive lead to the power source. Leave it connected for only a few seconds before disconnecting it again.

11. Describe what happened when you detached the power source from the 800-turn solenoid? Was there any difference when you reattached the power source to the solenoid?

- Switch the power source to the 9-V setting and disconnect, reconnect, and then disconnect the positive lead from the power source as you did at the 3-V setting.

12. Describe your observations when the 9-V setting was used for the primary circuit.

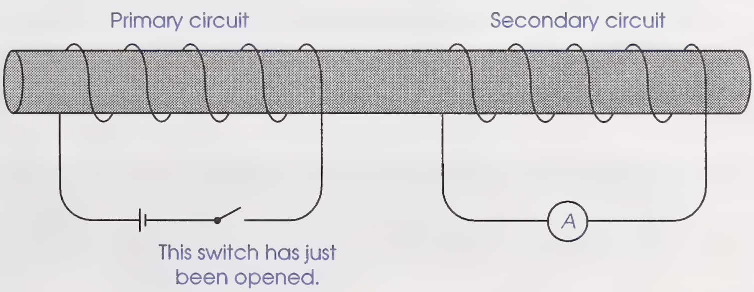
Analysis

13. How does connecting and disconnecting the solenoid in the primary circuit affect the magnetic flux that it creates?
14. What role does the steel bolt play in terms of the magnetic field between the solenoids?
15. Explain how the 400-turn solenoid could have a tiny current in it, even though it is not connected to the DC power supply.

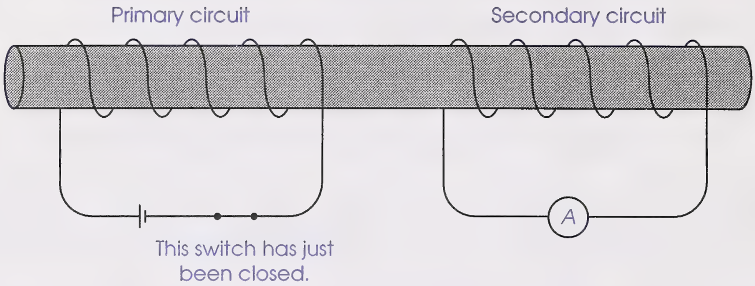
Conclusion

16. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams by following the directions in the questions.

    a. Draw the induced current and the induced magnetic field in the secondary circuit the instant the primary circuit is disconnected.

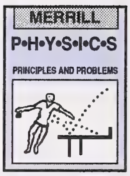


b. Draw the induced current and the induced magnetic field the instant the primary circuit is reconnected.

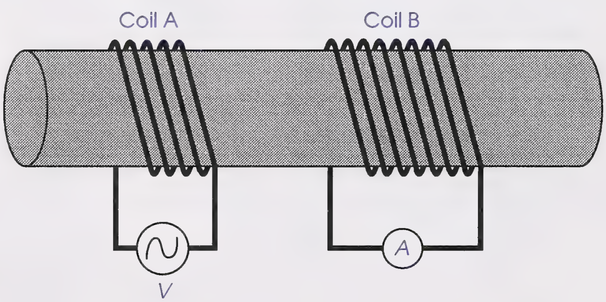


Check your answers by turning to the Appendix, Section 1: Activity 4.

One of the things you should have noticed in the investigation is a difference between the readings on the multimeter when switching from 3 V to 9 V. As a matter of fact, that change is one of the most useful of all the characteristics of a transformer. For more information on the way in which a transformer operates, carefully read the section on transformers on pages 526 and 527 of your textbook.



Refer to this simplified diagram of a transformer as you answer the following question.

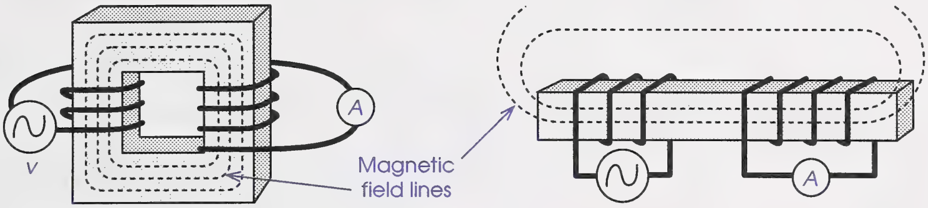


17. Which coil is the primary coil and which coil is the secondary coil? Explain your answer.

18. What is the difference between a step-up transformer and a step-down transformer?

Check your answers by turning to the Appendix, Section 1: Activity 4.

You may have noticed that the transformer illustrated in your textbook differs from the one that you used in this investigation. The transformers in the textbook forms a closed ring or loop. The ring or loop arrangement produces a transformer that is much more efficient than the simple bar that you used. This is due to the fact that all of the magnetic field lines from the primary cicuit are guided through the secondary circuit by the iron ring and stay within the ring. If a bar is used, some of the magnetic field lines escape into space and do not influence the induction between the coils. This is illustrated in the following diagrams.



The textbook introduces two new equations in its description of transformers. It's helpful to know the origins of these equations so that you can understand how to use them properly.

- The first equation comes from Faraday's work with electromagnetic induction.

Number of turns on primary → N_p; Number of turns on secondary → N_s

$$\boxed{\frac{N_p}{N_s} = \frac{V_p}{V_s}}$$

V_p ← Primary (input) voltage; V_s ← Secondary (induced) voltage

- The second equation comes from the law of conservation of energy.

$$\boxed{V_p I_p = V_s I_s}$$

Rearrange.

Primary (input) voltage → V_p; Secondary (induced) voltage → V_s

$$\boxed{\frac{V_p}{V_s} = \frac{I_s}{I_p}}$$

I_s ← Secondary (induced) current; I_p ← Primary (input) current

Since both equations contain $\frac{V_p}{V_s}$, they can be combined to give you the equation found in the Physics 30 data sheets.

$$\boxed{\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}}$$

Ideal transformer equation

19. Explain how the law of conservation of energy supports the second equation.

20. Refer to your answer to question 19 to explain why the equation applies only to an ideal transformer.

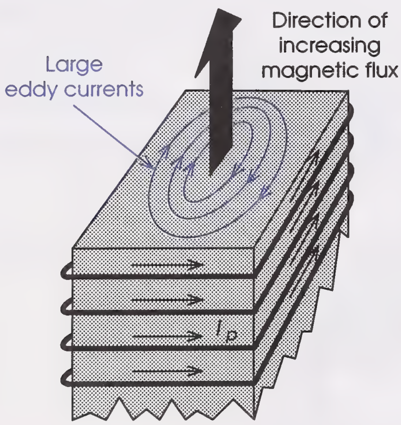
Transformers are not ideal. Thermal energy is generated within transformers. The following list describes the three main sources of thermal energy within a transformer:

- Thermal energy is generated within the many loops of copper wire due to the resistance of the wire.

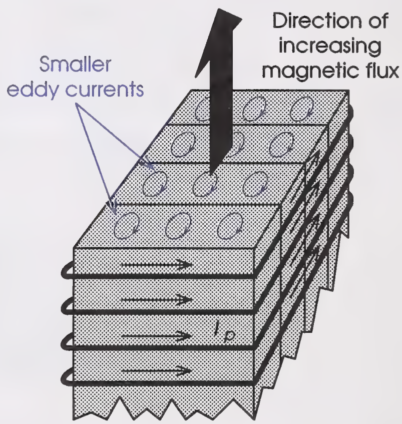
- Thermal energy is created by the magnetic domains bumping into each other as they constantly change directions within the core.

eddy currents – induced currents that unnecessarily heat the parts that they flow in

- Thermal energy is created by **eddy currents** that are induced to flow in the transformer core. Eddy currents are created by the same process that induces a current to flow in the secondary coil. As the magnetic flux through the core changes, currents are induced within the core to oppose that change, according to Lenz's law. To reduce this loss to thermal energy, the cores of most transformers are made with laminated sheets.



Solid Core



Laminated Core

The eddy currents within the laminated core are forced to move within the individual sheets. The average current is less in this case, so less thermal energy is created. This means that more energy is available to be passed on to the secondary coil.

21. Apply Lenz's law to verify the direction of the eddy currents in the previous diagrams.

22. Why is it important for the thin sheets within the laminated core to be coated with an insulating material like varnish?

Check your answers by turning to the Appendix, Section 1: Activity 4.

You may be surprised to know that even though thermal energy is created within a transformer, this is actually a very small portion of the input energy. Most transformers lose only 1 to 3% of this original input energy to thermal energy. Part of the reason is due to the fact that the transformer is a device with no large-scale moving parts, so there are no losses to frictional effects or sound. This means that the equation for an ideal transformer can reasonably describe most well-designed transformers.

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Study the Example Problem on page 527 of your textbook. Note that the transformer is assumed to be ideal and that the current and voltage values are effective, or rms, values since the transformer is an AC device.

23. Do Practice Problems 9 to 12 on pages 527 and 528 of your textbook.

Check your answers by turning to page 684 of your textbook.

One of the best applications of transformers concerns how your home is supplied with AC power. Even though the transmission lines that leave the generating station can have AC voltages between 100 000 V and 500 000 V, the power that enters your house is only 110 V or 220 V. It is interesting to know how and why this occurs. The following readings and questions from your textbook will highlight the main ideas of the process. In each case, pay close attention to the photographs and the key ideas that support each explanation.

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Read pages 447, 460, and 461 of your textbook.

24. Write a concise explanation of why high voltages are used in long-distance transmission lines.

Read the first paragraph on page 528 of your textbook. Note Figure 25-12 in the upper left corner.

25. a. Write a concise description of the type of transformer that lowers the voltage before it enters a consumer's home.

b. Use an equation to help explain the principles behind the design of this device.

26. Do Problems 13 and 17 on page 533 of your textbook. Be sure to begin each solution with a labelled diagram.

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To find out what the future may hold for the transmission of electricity, read the Physics and Technology section on page 463 of your textbook.

27. a. What is a UHV transmission line?

b. Why are UHV transmission lines likely to be needed in the future?

Check your answers by turning to the Appendix, Section 1: Activity 4.

You should now have a very clear idea of how electromagnetic induction affects your life. In this activity you examined many applications, but the most significant was probably the transformer, since this device allows consumers to be supplied with electricity at a great distance from the place where the power is generated.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

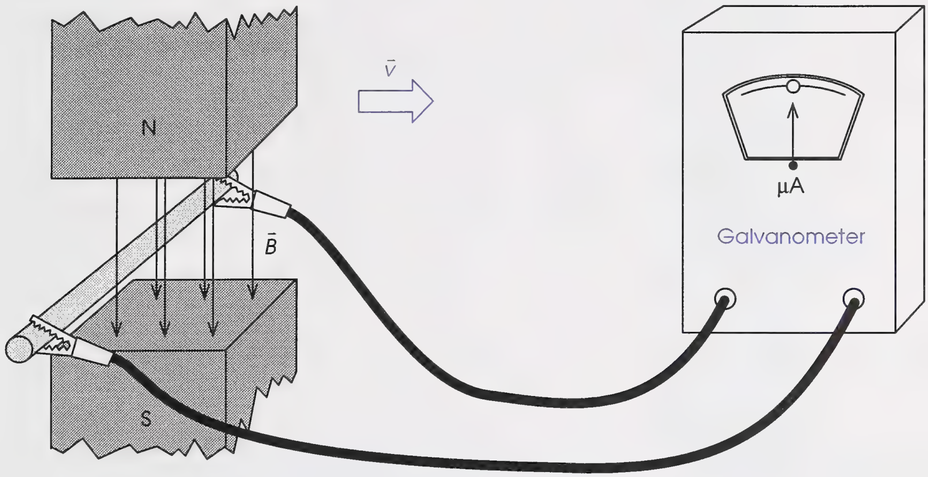
Extra Help

In this section you have seen that electromagnetic induction can be explained in terms of magnetic flux and in terms of a conductor cutting magnetic field lines.

A current is induced in a conductor when that conductor cuts magnetic field lines. The direction of the induced current is determined by the hand rule for force.	A current is induced in a loop when the magnetic flux through that loop changes. The direction of the induced current is determined by Lenz's law.

As the following question will indicate, these two approaches are actually not all that different from each other.

1. Imagine that the straight wire is pulled to the right so that it passes through the region between the magnets.



   a. Use the fact that the straight wire cuts magnetic field lines and the right-hand rule for force to determine the direction of the induced conventional current through the wire.

   b. The straight wire can be seen to be a part of a loop which also includes the galvanometer. Use this fact and Lenz's law to determine the direction of the induced current through the wire.

   c. Is there a difference between your answers to part a. and part b. of this question?

   d. In this situation, is it possible for the magnetic flux through the loop to change without part of the loop cutting magnetic field lines?

   e. Compare the two approaches to electromagnetic induction.

In this section you have learned some important new terms and equations. The next question will help you to summarize these ideas.

2. Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Complete the chart in your notebook.

Term	Definition	Symbol	Units	Equation
Induced EMF				
Effective Current				
Effective Voltage				
Magnetic Flux				
Back-EMF				
Secondary Voltage				

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following activities.

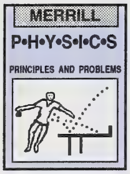
1. If you have access to the *Enrichment* booklet which accompanies the teacher resource package for your textbook, do the enrichment activity for Chapter 25, The Induction Coil. This activity will allow you to apply your knowledge of induction to the design and function of a car's ignition system.

2. Transformers

   To increase or maintain the efficiency of a transformer, it is necessary to reduce the heat lost to the external environment. This involves insulating the transformer. A second condition is that hot spots must be avoided. The heat generated by a transformer may be considerable. Hot spots increase the resistance of any conductor and increase the likelihood of a burnout. Most transformers use a liquid as an insulator. Older transformers used a class of substances called polychlorinated biphenyls, or PCBs. PCBs have been in the news a lot in recent years. They have the useful properties of being extremely stable, having a high boiling point, and being unreactive. In addition, PCBs are non-flammable, making them easy to store and

transport. There is some thought that PCBs may contain small amounts of deadly impurities that become reactive when heated and that have been linked to some forms of cancer. This being so, federal regulations to prohibit the manufacture of transformers containing PCBs were put in place in 1980. Newer transformers use other liquids with properties similar to PCB, but which have not yet been linked to cancer. Unfortunately, many of these other liquids are more toxic than PCBs and represent other dangers if you are exposed to them.

a. A large transformer filled with transformer oil is never a good thing to tamper with or take apart unless you are a trained professional. Explain why.



Read the last paragraph on page 528 of your textbook to learn of some of the uses of transformers in your daily life.

b. List some of the purposes of transformers. Which use plays the most important role in your daily life? Justify your answer.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you discovered the operating principles behind mechanical generators and transformers. Using these principles you have solved problems relating to the generation and transfer of electric energy between a magnetic field and a nearby electric conductor. In the next section you will continue with the nature of electromagnetic transfer of energy through space in the absence of an electric conductor.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

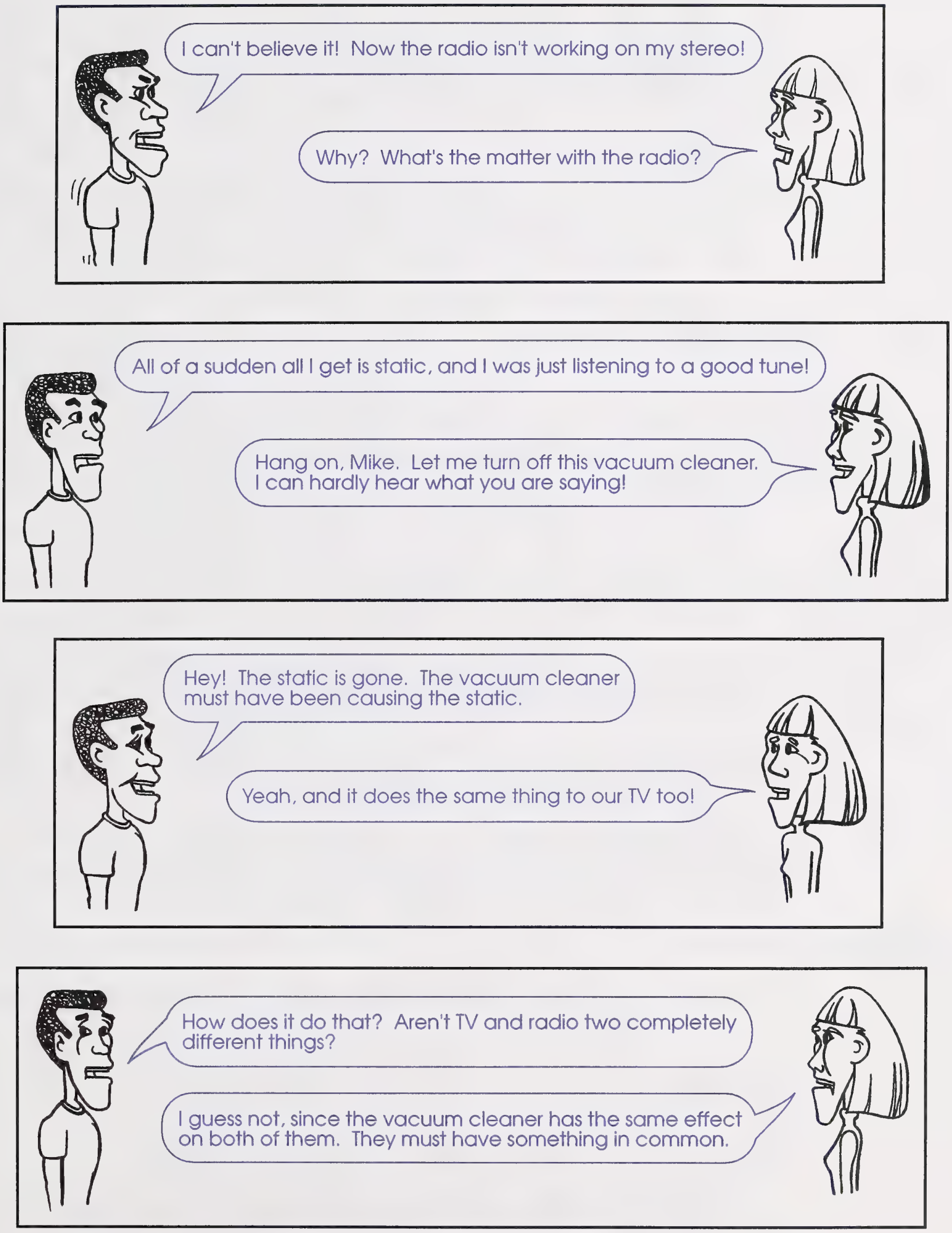
2 Electromagnetic Waves

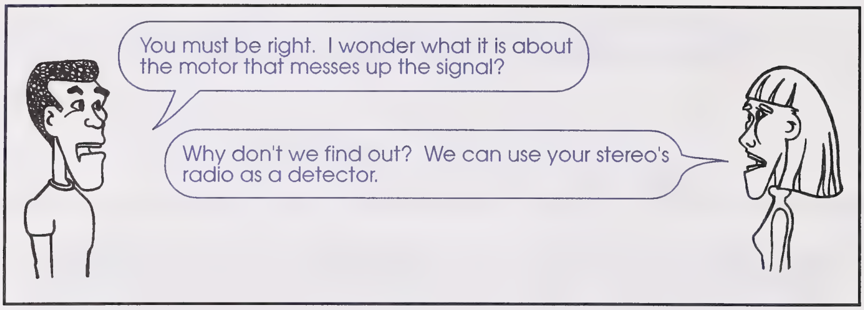
WESTFILE INC.

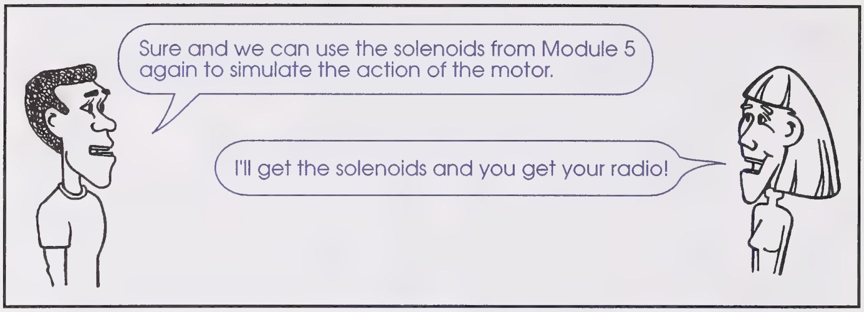
What does a speed limit mean to you? A speed limit is the maximum speed that you are allowed to operate your vehicle at under ideal conditions – dry pavement and maximum visibility. However, many motorists don't seem to understand this, as indicated by the number of speeding tickets and vechicle-related deaths every year. Police officers can be very accurate at determining the speed of a vehicle using a new laser light system that may eventually replace the traditional radar gun system. Why is the new laser light system more accurate? Is laser light similar to radar? What is radar?

In Section 1 you were introduced to the principles behind electromagnetic induction. In this section you will continue with the concept of electromagnetic induction, but will extend the concept to include the transfer of energy through space in the form of an electromagnetic wave. At the end of this section you should be able to summarize the events which occur in the creation or reception of electromagnetic radiation (EMR), predict and explain the propagation of EMR in relation to electromagnetic induction, solve mathematical problems relating to the wave properties of EMR, and perform simple experiments and simulations relating to the wave properties of EMR. In addition, you should be able to use your knowledge of wave properties to compare and contrast specific regions of the electromagnetic spectrum, including radar and visible light.

Activity 1: Experiencing Electromagnetic Waves







1. Mike and Nicole assume that it is the motor of the vacuum cleaner that is responsible for the interference with the radio. Why would they assume that?

2. Mike referred to using the solenoids to simulate the action of a motor. In what way do your solenoids resemble an electric motor?

In the next investigation you will have an opportunity to observe the phenomenon that Mike and Nicole were talking about.

Investigation: Induction at a Distance

Science Skills

- ❑ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ❑ D. Analysing
- ❑ E. Synthesizing
- ❑ F. Evaluating

Purpose

In this investigation you will explore the possible link between electromagnetic induction and radio waves.

Materials

You will need the following materials for this investigation:

- the 800-turn solenoid constructed in Module 5
- a steel bolt
- a variable power supply capable of 12-V DC output

- a radio, preferably portable
- a 30-Ω power resistor rated at 5 W

Caution

Important Safety Precautions

It is very important that you read and then apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.

- Only replace the fuse inside the meter with the specified or approved equivalent fuse.

- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.

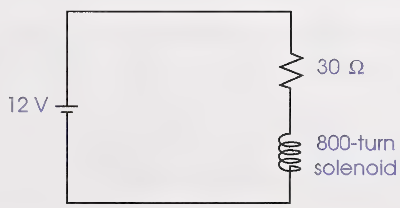
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure

- Read through the entire procedure before starting the investigation.

- Without turning on the power supply, construct the following circuit. Note that the power supply should be on the 12-V setting.



- Insert the steel bolt through the 800-turn solenoid.

- Turn your radio so that is **not** receiving any particular station. Place your radio about two meters away from the 800-turn solenoid.
- Turn up the volume of the radio to the maximum setting. Since the radio is not on a station, you should hear only static noises.
- While carefully listening to the static noise from the radio, turn on the DC power supply. Connect and disconnect the lead between the DC power supply and the solenoid. Listen for any changes in the static noise as you do this.

3. Describe the change in the sound being output by the radio when the solenoid was disconnected and reconnected to the power source.

4. It is also a good idea to check the assumption that it is the solenoid causing the difference. What would happen if both leads were disconnected from the solenoid and touched together very briefly? Make sure that the power resistor is still in the circuit and try it.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Analysis

5. In Section 1 you used the 800-turn solenoid and the steel bolt as a part of a transformer. In order to observe an effect in that experiment, you had to disconnect and reconnect the solenoid to the DC power supply. What enabled the primary solenoid to influence the secondary solenoid in that investigation?

Interpretations

6. Based on your answer to the previous question, speculate on what enabled the solenoid to influence the radio.

7. Your work with transformers has always involved an iron or steel core linking the primary and secondary circuits. Is there such a link in this investigation?

8. A radio is designed to receive radio waves. The radio's reception circuitry somehow responded to the changing magnetic fields of the solenoid. What does this suggest about the nature of radio waves?

Check your answers by turning to the Appendix, Section 2: Activity 1.

The previous investigation suggested that the magnetic fields produced by the solenoid travel through the 2 m of space between the solenoid and the radio and influence the radio's circuitry. You may be surprised to know that there was also an induced electric field present that travelled with the induced magnetic field in the form of an **electromagnetic wave**.

electromagnetic wave – a wave of changing electric and magnetic fields that travels through space

There are a number of types of electromagnetic waves. In the previous investigation you made a radio wave with your solenoid circuit. Other types of electromagnetic waves would include radar, microwaves, x-rays, and gamma rays. What you might find most surprising of all is the fact that light is also an electromagnetic wave.

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To find out more about electromagnetic waves, read the last paragraph on page 542 and the first three paragraphs on page 544 of your textbook. Be sure to carefully study Figure 26-5 as you complete the reading.

9. Who first predicted the existence of electromagnetic waves?

10. What does a changing magnetic field produce? Sketch a diagram to support your answer. How do your answer and sketch differ from similar things that you sketched in Module 3?

11. What does a changing electric field produce? Sketch a diagram to support your answer.

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12. Refer to the answers to the previous two questions to describe how an electromagnetic wave propagates through space. Make a sketch of Figure 26-7 on page 545 of your textbook as part of your answer.

13. What initiates an electromagnetic wave?

14. What value led Maxwell to speculate that light itself was an electromagnetic wave?

Check your answers by turning to the Appendix, Section 2: Activity 1.

The implication of Maxwell's work was that the separate studies of electricity, magnetism, and light now came under the general name of **electromagnetic radiation**. As the definition implies, radio waves, microwaves, and visible light all transfer energy through space in the form of electromagnetic waves. Even though these waves all travel at the same speed through a vacuum, they have different wavelengths and frequencies.

electromagnetic radiation – energy carried by electromagnetic waves through space

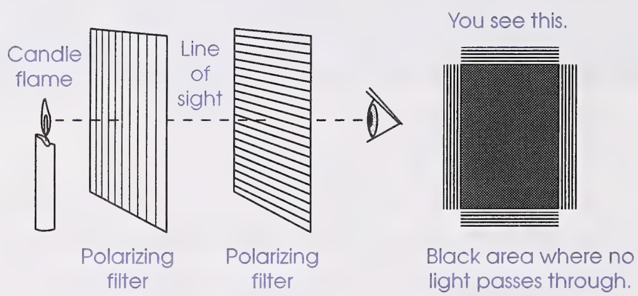
Do you remember the meanings of the terms *wavelength* and *frequency*? Throughout the remainder of this module you will be asked to recall terms and ideas from your study of waves in Physics 20. You may find it helpful to use the index of your textbook to look up relevant explanations and examples as you complete the upcoming activities.

Activity 2: The Nature of Electromagnetic Waves

How can light travel through the vacuum of space? After all, don't all waves need a medium? If there is a special medium for light that fills all space, how could it be detected?

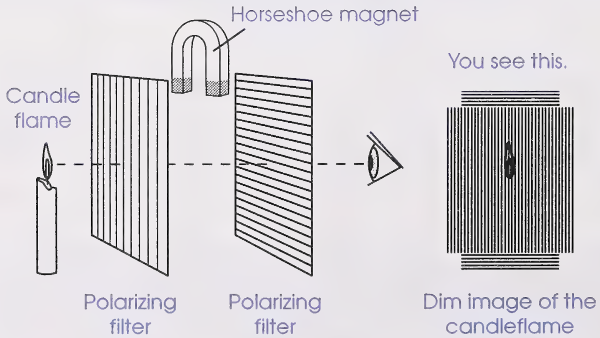
These questions stumped some of the greatest minds in the scientific community for a very long time. It's curious that the first ideas about the nature of light as a form of electromagnetic radiation came about because a physicist had stage fright!

In 1846 Sir Charles Wheatstone was to give a lecture to the Royal Institution, a prestigious forum for presenting scientific papers and ideas. Michael Faraday, acting as host for the evening, was forced to fill in for Wheatstone at the absolute last minute when Wheatstone looked at the audience, panicked, and ran out of the theatre. Faraday, left with an unruly mob of disappointed physicists, decided to outline an experiment in which he arrived at some perplexing results. The following diagram shows part of Faraday's experiment.



1. Why would you not see an image of the candle flame when you look through the filters in the previous diagram? Explain your answer.

If a magnetic field was put in place between the two polarizing filters, the results changed.



This represented concrete proof to Faraday that a magnetic field could somehow influence the plane of polarization of light. That in itself was startling, but Faraday went on to speculate that electricity, magnetism, and light were all interconnected! He and Oersted had shown that electricity and magnetism were linked together, and this experiment showed that magnetism and light were connected, which led to the assumption that they were all connected! Faraday put forward the idea that light was a vibration of electric and magnetic field lines, but was unable to fit a mathematical model to the idea.

This experiment by Faraday is similar to the investigation that you did in the previous activity. It suggests a possible connection, but does not prove it or explain it.

THE BETTMAN ARCHIVE

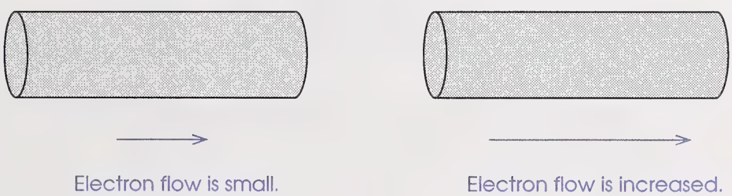
James Maxwell put Faraday's speculation into mathematical form. Maxwell was able to work out four simple equations that describe all of the varied phenomena of electricity and magnetism. These equations also showed that electricity and magnetism could produce an electromagnetic wave that travelled outward from the source.

When Maxwell calculated that these electromagnetic waves travelled at the speed of light, he suggested that light itself was an electromagnetic wave. He also predicted the existence of a number of other electromagnetic waves, with wavelengths differing from those of visible light.

You can learn more about Maxwell's work by watching a videocassette.

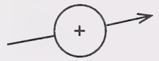
The video series *Wave-Particle Duality* contains a ten-minute program called *The Electromagnetic Model*. Familiarize yourself with the following questions prior to watching the program. This will help you to focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

2. According to Oersted, wire that is carrying electron flow will generate a magnetic field that circles around the wire. Copy the following diagrams into your notebook. Complete the diagrams to show the change which occurs in the magnetic field around the wire when the electron flow increases. Make sure you indicate the direction of the field.

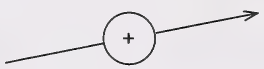


3. Describe a process by which the reverse could occur. How can a magnetic field be used to create an electric current?

4. The wire is not absolutely necessary. Free electric charges moving through space also create magnetic fields. Copy the following diagrams into your notebook. Complete the diagrams by indicating the size and direction of the magnetic field which surrounds an electric charge moving at the indicated speed.

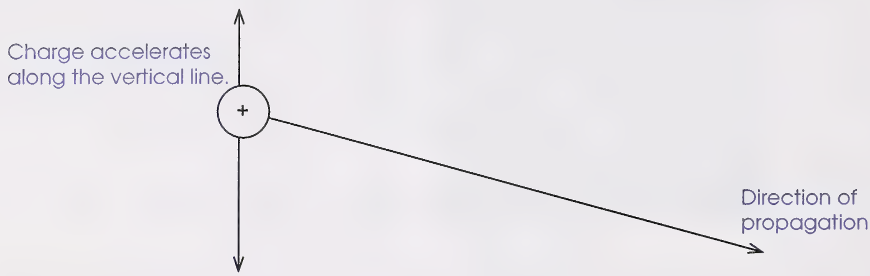


Charge is moving at a constant speed.

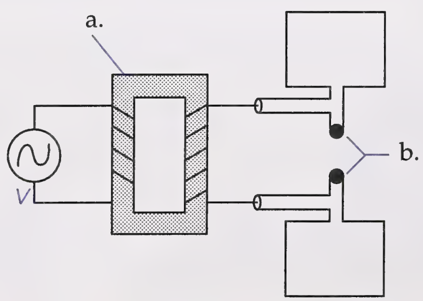


Speed of moving charge has increased.

5. Maxwell calculated that an accelerating, or oscillating, charge would create a special type of electric field. Copy the following diagram into your notebook. Complete the diagram by showing the electric field created by a particle oscillating along a straight line.



6. In 1887 Heinrich Hertz set out to find evidence for the existence of the waves predicted by Maxwell. Provide the correct name for each of the indicated parts in the diagram.



7. The device in the previous diagram is called a transmitter. Describe the function of each of the parts indicated in the previous question.

8. What did Hertz use as a detector for the waves transmitted by this device? How did Hertz know that he had detected those waves?

9. The waves that Hertz detected would be called radio waves today. Maxwell's theory predicted that a range of wavelengths should be found. This range of wavelengths is referred to as the **electromagnetic spectrum**. List the types of electromagnetic waves from largest to smallest wavelength.

electromagnetic spectrum – the complete range of electromagnetic waves ordered according to frequency or wavelength

Stop the videotape at the end of the program.

Check your answers by turning to the Appendix, Section 2: Activity 2.

How would you calculate the frequency or wavelength of an electromagnetic wave? The answer, according to Maxwell, was simple! Fortunately the complex equations used by Maxwell reduced down to a simple equation that you are familiar with from Physics 20, the universal wave equation $(v = f\lambda)$. The only difference is that electromagnetic waves always travel at the speed of light, c, in a vacuum or air, so the equation becomes $c = f\lambda$.

As an example, police radar guns use electromagnetic waves that have a frequency of about 1.0×10^{10} Hz. The wavelength of these electromagnetic waves could be calculated as follows.

$c = 3.00 \times 10^{8}\ \text{m/s}$

$f = 1.0 \times 10^{10}\ \text{Hz}$

$\lambda = ?$

$$
\begin{aligned}
c &= f\lambda \\
\lambda &= \frac{c}{f} \\
&= \frac{3.00 \times 10^{8}\ \text{m/s}}{1.0 \times 10^{10}\ \text{Hz}} \\
&= 3.0 \times 10^{-2}\ \text{m}
\end{aligned}
$$

10. Red light has a frequency of 4.8×10^{14} Hz, while an AM radio station broadcasts on a frequency of 740 kHz.

    a. Calculate the wavelengths of these electromagnetic waves.

b. Compare your answers to the wavelength of the waves emitted by the police radar gun.

c. A motorist's radar detector uses an antenna and circuitry that is tuned to electromagnetic waves with a wavelength of about 3.0 cm. Why won't the radar detector be able to detect the red light from a police officer's laser speed system?

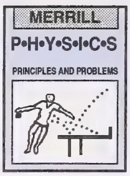
11. A beam of red light with a frequency of 4.78×10^{14} Hz travels from air into water. Its speed in air is 3.00×10^{8} m/s, while its speed in water is 2.256×10^{8} m/s.

a. Calculate the wavelength of the red light in air and water.

b. Compare the frequency of the red light in air and water. Explain your answer.

c. Why do many scientists prefer to describe the components of the electromagnetic spectrum in terms of frequency instead of wavelength?

d. Why do many students find it useful to remember the universal wave equation as $\lambda = \frac{v}{f}$?



12. Do Applying Concepts question 7 on page 552 of your textbook. Note that this question is in the column on the right-hand side of the page.

13. Outline the similarities and differences between the mechanical waves (sound or water waves) that you studied in Physics 20 and the electromagnetic waves that you are learning about now.

Check your answers by turning to the Appendix, Section 2: Activity 2.

In the next activity you will take a closer look at the properties and applications of the different types of electromagnetic waves.

Activity 3: Exploring the Electromagnetic Spectrum

What makes a radio wave different from a microwave? How is infrared radiation different from gamma radiation? How are these electromagnetic waves used in different technologies? What parts of the electromagnetic spectrum have the greatest impact on your life?

In this activity you will answer these questions as you survey the electromagnetic spectrum. Each type of electromagnetic wave will be described by answering the following questions:

- What is the range of frequencies for this kind of wave?
- How is this type of wave produced?
- How can this type of wave be detected through its interaction with matter?

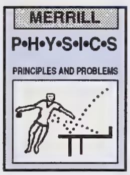
This format of presentation will be used with each type of wave so that you can identify trends and readily compare and contrast the different wave types.

Radio Waves

Radio waves occupy a region of the electromagnetic spectrum from 100 kHz to about 500 MHz. This part of the spectrum includes AM and FM radio signals and TV broadcasting signals. Radio waves occur naturally due to lightning strikes on Earth and due to the behaviour of atoms and molecules in outer space. Artificial radio waves are created by causing electrons to oscillate in a broadcast antenna at a frequency called the carrier frequency. The electromagnetic waves created by this antenna have the same frequency as the oscillating electrons.

carrier frequency – the frequency used to carry a communication signal

To find out how an antenna creates electromagnatic waves, read the last paragraph on page 544 and the first paragraph on page 545 in your textbook. Take careful note of Figures 26-6 and 26-7.



1. Do Reviewing Concepts questions 5 and 6 on page 552 of your textbook.

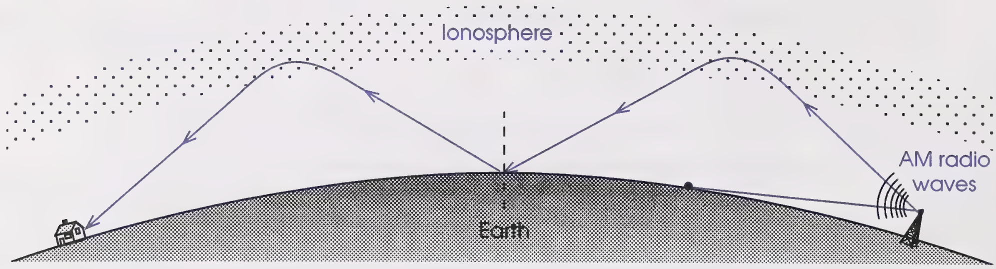
Radio waves are used extensively for communication because they are the easiest to produce and detect. It's important to realize that the carrier wave can be used to carry information in a number of different ways.

AM Radio

When the radio waves have the signal coded in the amplitude of the wave they are said to be **amplitude modulated**, or AM, waves. These waves exist in a band from 500 kHz to 1600 kHz.

AM radio waves have the interesting property of being able to reflect off a layer of charged particles in the upper atmosphere, called the ionosphere. This means that if there is sufficient energy in the signal, these waves can be bounced off the ionosphere and then detected hundreds or even thousands of kilometres away.

ionosphere – an upper layer of the atmosphere containing charged particles

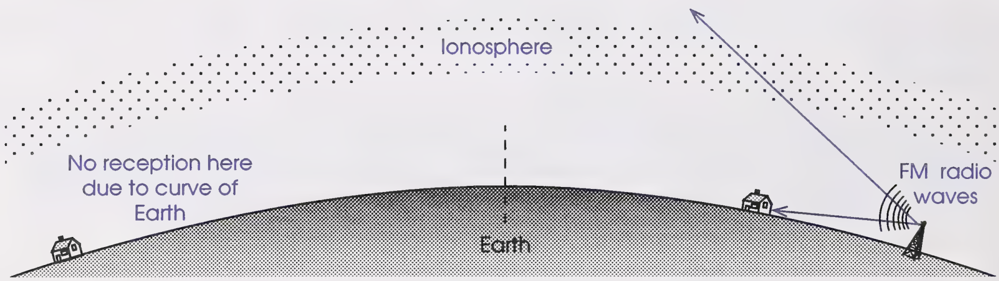


The signal can also bounce off the earth and greatly increase the range of transmission. Otherwise the curve of the earth would greatly reduce the range of the signal.

FM Radio and TV

Radio waves that have the signal coded in the frequency of the wave are said to be **frequency modulated**, or FM. This description also includes TV signals. TV channels 2 through 6 can be found in a band from 54 MHz to 88 MHz, while channels 7 through 13 are broadcast in a band between 174 MHz and 216 MHz. FM radio is broadcast between these two sets of TV channels at 88 MHz to 108 MHz.

These frequency modulated bands do not bounce off the ionosphere, so their reception area is limited by the curve of the earth. This means that the usual broadcast range is usually less than 100 km.



One advantage of this property is that these signals can be used to communicate beyond the planet (the moon) since the signals can penetrate the atmosphere.

2. Calculate the range of wavelengths for the FM radio band.

3. Explain why TV broadcast reception can be affected by a low-flying aircraft, while an AM radio broadcast is unlikely to be affected. You should mention the concept of scattering in your answer.

4. Explain why AM radio waves are less affected by buildings than FM radio waves. Your answer should mention the concept of diffraction.

The reception of all types of radio waves is the inverse process of how they are created. Instead of a broadcast antenna generating the waves, the waves induce oscillating charges in the antenna of the receiver.

You can find out more about how the antenna of a receiver collects radio waves by reading page 535 and the section called Reception of Electromagnetic Waves on pages 549 and 550 of your textbook.

5. Do Concept Review questions 2.2 and 2.3 on page 551 of your textbook.

6. Do Reviewing Concepts questions 8 and 9 on page 552 of your textbook. These questions are in the left column on that page.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Microwaves

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This band of the electromagnetic spectrum occupies a region from about 10^9 Hz to 10^{11} Hz. Even though you may first think of microwave ovens, this band also includes radar and telecommunication signals.

This band is far removed from the AM range, and therefore the effect of reflection from the ionosphere has little influence on these signals. This is why this band is preferred for satellite telecommunication systems.

Unlike the radio waves that you examined earlier, microwaves require higher frequencies that are difficult to produce with an electronic circuit and antenna. These waves are usually created by charges vibrating in a resonant cavity that determines the frequency of the wave. If you have a microwave oven, it will contain such a cavity.

When microwaves strike matter, they can accelerate electrons within molecules, causing thermal energy to be produced. Most microwave ovens operate at a frequency of 2.45×10^9 Hz, since this frequency is particularly effective at exciting water molecules.

7. Calculate the wavelength of the electromagnetic waves generated by most microwave ovens. Assume that the microwaves are travelling through air.

8. Do Reviewing Concepts question 4 on page 552 of your textbook. This question is in the left column on that page.

9. Do Applying Concepts question 9 on page 552 of your textbook. This question is in the right column on that page.

Infrared Radiation

Electromagnetic waves with a frequency of about 10^{11} Hz to 10^{14} Hz are usually classified as infrared radiation. These waves have a frequency that matches the natural rate of vibration of most molecules. This describes how these waves are created and detected. Warm objects will emit infrared radiation because their molecules are vibrating within this frequency range. Similarly, if you hold your hand close to a hot object, you will feel the result of the infrared radiation being emitted as a warm sensation in your hand.

As the name implies, these rays are *almost red*. The infrared waves with the shortest wavelengths have properties very similar to the visible spectrum. For example, infrared detectors can be used to identify areas of heat loss in buildings or regions of abnormal blood flow in the body by using a special type of film that is sensitive to this type of radiation.

10. Explain why infrared detectors are so useful in search-and-rescue operations, particularly when looking for people at sea or in dense bush.

11. What is the range of wavelengths for infrared radiation travelling in a vacuum?

An interesting application of infrared radiation is global warming, or the greenhouse effect, which is described in the Physics and Society section on page 548 of your textbook. Read this article and be especially aware of the role of infrared radiation.

12. Answer question 3 which appears at the end of the Physics and Society section on page 548 of your textbook.

Visible Light

The human eye is sensitive to electromagnetic waves with a frequency of 4.0×10^{14} Hz to 7.5×10^{14} Hz. When compared to the other types of electromagnetic radiation, this is a very narrow band within the whole electromagnetic spectrum.

Visible light is created by the movement of electrons within the energy levels of atoms. In a similar way, visible light can be detected when the electrons within atoms absorb energy. You'll learn more about these processes in the last modules of the course.

When visible light strikes atoms, the outcome is often chemical change. The development of photographic film and the process of photosynthesis are examples of chemical changes caused by light.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

To get a better sense of how visible light fits into the whole electromagnetic spectrum, read pages 330, 337 (including the Physics and Technology section), 338, and 339 in your textbook.

13. Explain how the name Roy G Biv is helpful for remembering the order of the colours in the electromagnetic spectrum.

14. What principle have people learned to assume to be true in the process of vision?

15. Describe the components of white light.

16. Why don't compact discs wear out as fast as phonograph records?

17. What technology utilizes the additive colour theory?

18. What is the difference between a dye and a pigment?

Check your answers by turning to the Appendix, Section 2: Activity 3.

Ultraviolet Light

This type of electromagnetic wave occupies a frequency band from about 8×10^{14} Hz to 3×10^{17} Hz. As the name implies, this frequency range exists in a region beyond violet. Ultraviolet light is similar to visible light in that it is caused by electron energy transitions within atoms and it can cause chemical reactions in which radiant energy is used to break chemical bounds. The big difference is that this form of radiation delivers much more energy to a chemical reaction than visible light does.

One example of this type of reaction is the creation of ozone in the upper atmosphere. When ultraviolet light collides with oxygen molecules (O_2) in the upper atmosphere, the oxygen atoms are separated from each other and they combine with another oxygen molecule to form ozone (O_3).

Although the ozone layer is a very low-density veil of gas, it has an important function because it can absorb wavelengths of ultraviolet light that are not absorbed by any other atmospheric components.

Another example of a chemical reaction caused by ultraviolet light is the breaking of chemical bonds within skin cells that are exposed to ultraviolet light. Long-term exposure to ultraviolet light can lead to an increased risk of skin cancer, blotchy skin discoloration, and premature aging.

19. Do Concept Review question 2.4 on page 551 of your textbook.

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In response to the injury to your skin caused by ultraviolet light, your skin produces melanin, a pigment that helps to filter out some of this harmful radiation. This tends to darken your skin and most people refer to the whole effect as a sun tan.

Despite the fact that many people think that a sun tan is a sign of good health, it is actually evidence of damaged skin cells. People with fair skin (blondes and redheads) often can't produce enough melanin to provide protection for their skin, so their skin is more likely to burn than to tan.

The best way to protect your skin from the sun is to stay out of the sun when the ultraviolet rays are the most intense – from 11:00 a.m. to 3:00 p.m. (daylight saving time). If you must be out in the sun during this time, you should wear long sleeves, pants, and a wide-brimmed hat. If you are going swimming, a broad-spectrum sunscreen is recommended. Sunscreens are rated according to SPF, which stands for sun protection factor. The SPF of a sunscreen relates the amount of time that it would take your skin to burn without any protection to the amount of time it would take your skin to burn when wearing the sun screen. An SPF of 8 would supposedly allow you to stay out in the sun 8 times longer before burning. Most dermatologists recommend a sun block with an SPF of 15 or higher. However, since most people do not apply the sunscreen well in advance of being in the sun (so the skin can properly absorb this protection), and since most people do not reapply it often enough, these SPF ratings are best interpreted to relate to the amount of protection offered to your skin during unavoidable sun exposure.

A popular misconception is the idea that a tan helps protect your skin from the sun. Most dermatologists would argue that a tan indicates that your skin has already been damaged by the sun and that an average tan is only equivalent to a SPF of 3 or 5, which is inadequate in most situations. This information is contrary to the messages promoted by the operators of some tanning parlours, who claim that an artificially induced tan will help protect your skin.

20. Why do many people seek a deep, bronze-coloured sun tan?

21. Describe the hazards associated with long-term exposure to the sun.

22. Combine your answers to the previous two questions to concisely outline the risks and benefits associated with excessive tanning.

Check your answers by turning to the Appendix, Section 2: Activity 3.

X-rays

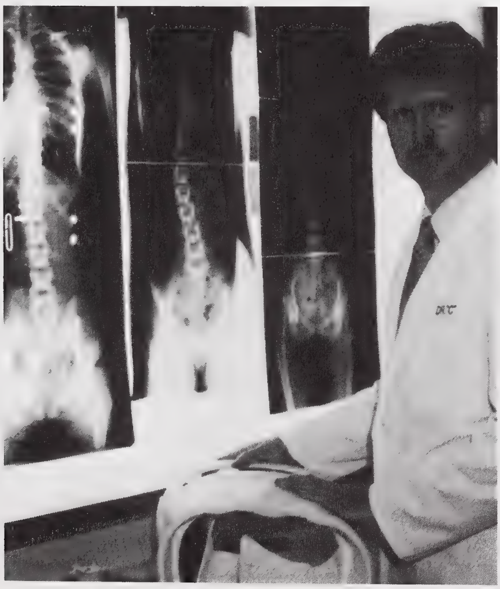
X-ray radiation is usually classified in a band from about 3×10^{17} Hz to about 5×10^{19} Hz, although it is possible to have x-rays with frequencies as high as 10^{25} Hz. X-rays have even more energy than ultraviolet light and therefore are potentially more dangerous.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

To find out how x-rays are created, read the section called X-Rays on pages 550 and 551 of your textbook.

23. How are x-rays produced?

24. Why does the face plate glass of a TV contain lead?



NASA

The penetrating power of x-rays has made them an excellent diagnostic tool for medicine. The x-ray in the centre is from a person with scoliosis, a disease characterized by progressive curvature of the spine. The x-ray on the left shows the improvement over time that is possible through the use of a high-technology back brace.

Another application of x-rays in medicine is shown on the cover of this module. In this case low-energy, or "soft", x-rays are used to produce images of the heart. The photograph shows the x-ray images of the heart on the monitors. The cardiologist can use these images to help guide a special catheter that is used to clear a blocked artery.

It is interesting to note that the new technology here is not the x-rays, but rather the computer imaging system which is used to add detail to the images. An enhanced image helps the cardiologist to be more accurate and increases the chances for a successful procedure. This particular imaging system is a spin-off of image processing technology that was originally developed for NASA satellites that were surveying Earth's surface from space.

25. Cardiologists who have access to cardiac imaging technology claim that one of the system's greatest strengths is that they can use a non-surgical technique to get in and out of the heart as quickly as possible. Why are these characteristics so important?

Although x-rays are very useful, they should not be used indiscriminately. X-rays are classified as a type of ionizing radiation, because when an x-ray strikes an atom, it can ionize the atom. This occurs by the x-ray losing its energy to one of the atom's electrons, which in turn causes the ionization. In living tissues this ionization may affect a cell part directly, such as a mitochondrion, or it may effect other molecules needed by the cell, such as water. This may lead to the malfunction or death of the cells and eventually to the death of the whole organism.

The most serious effects occur when x-rays cause changes in a cell's DNA, which is the most important material in the cell. This helps explain why cells are most sensitive to x-ray radiation when they are actively growing. This is when they replicate (copy) DNA and undergo cell division. Since the DNA strands are being copied, there is a time just before cell division when there is twice the genetic material in the cell. This creates a larger target for the x-rays. The most sensitive cells in the body are those that do the most active dividing. In adults this means that cells found in bone marrow, skin, and the lining of the intestine are the most sensitive to ionizing radiation. Excessive radiation exposure in these areas often leads to cancers.

26. Why are fetuses and infants much more readily harmed by ionizing radiation than adults?

27. Why are x-rays not recommended for pregnant women?

28. Although ionizing radiation is hazardous, why is it misleading to say that all types of radiation are bad? Support your answer with examples.

Gamma Rays

Gamma radiation is considered to be the most damaging form of electromagnetic radiation. Gamma rays are mainly emitted by the unstable nuclei of natural or artificial radioactive materials. You'll learn more about this process in future modules. Although the gamma ray portion of the electromagnetic spectrum overlaps the x-ray portion, it is the way that each type of ray is created that separates the two. Most gamma ray radiation has a frequency higher than 5×10^{19} Hz. Gamma rays are similar to x-rays in

that they are considered a type of ionizing radiation, but the penetrating ability of gamma rays and their higher energy content makes them a more serious threat to living tissues. The effects of gamma radiation are much more severe than those of x-rays.

29. Cancer cells are often characterized as cells that are rapidly growing out of control. Why would these cells be particularly vulnerable to gamma rays from a source like radioactive cobalt 60 as a treatment for cancer?

Check your answers by turning to the Appendix, Section 2: Activity 3.

This activity was meant to be an overview of the many types of electromagnetic radiation. Many of the topics that were introduced here will be presented in detail in future modules.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

In this section you learned about the many types of electromagnetic waves. Use Figure 26-8 on page 546 of your textbook and the information presented in this section to help complete the following summary.

Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Complete the chart by recording the appropriate information under each heading. Note that the chart headings continue on the following page.

	Radio Waves	Micro-waves	Infrared Radiation	Visible Light	Ultraviolet Light	X-Rays	Gamma Rays
Range of Wavelengths in Air (m)							
Sources							

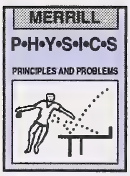
	Radio Waves	Micro-waves	Infrared Radiation	Visible Light	Ultraviolet Light	X-Rays	Gamma Rays
Possible Detectors							
Applications							

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do **one** of the following activities.

1. If you have access to the *Enrichment* booklet which accompanies the teacher resource package for your textbook, do the enrichment activity for Chapter 26, Radio Waves. This activity will allow you to extend your understanding of how electromagnetic waves are used in communication systems.



2. The Physics and Society section on page 529 of your textbook introduces a topic that concerns many people. Carefully read the section and answer the following questions.

   a. What is ELF radiation?

   b. Why was ELF radiation originally not thought to be a hazard to tissue cells?

   c. Evidence has been found that ELF radiation does influence cells. List the effects of ELF radiation on tissue cells.

   d. Why is there no clear consensus on the danger of ELF radiation?

   e. Summarize the evidence that has been found that has shown ELF radiation to be an environmental hazard.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you were introduced to the ways that electromagnetic radiation is created, transmitted, and received. You studied the factors which influence the type of electromagnetic wave detected by an antenna, and some of the experimental evidence for those waves. You should now be able to solve mathematical problems relating to the frequency, wavelength, and speed of an electromagnetic wave. You should also be able to describe the basic features of the electromagnetic spectrum and compare and contrast parts of the spectrum.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

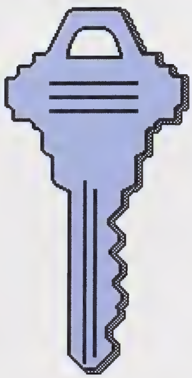
MODULE SUMMARY

In this module you have seen that the currents induced by a changing magnetic field can be put to work in a number of technologies. Generators, motors, and transformers all operate on the principle of electromagnetic induction.

You have also seen that the mutual induction of electric and magnetic fields can create electromagnetic waves. The applications of electromagnetic waves touch virtually every aspect of your life.

In the remaining modules of the course you will examine the processes behind many of these applications in greater detail.

Appendix



Glossary

Suggested Answers

Glossary

back-EMF: the induced EMF in a motor that acts to oppose the motion of the motor

carrier frequency: the frequency used to carry a communication signal

eddy currents: induced currents that unnecessarily heat the parts that they flow in

effective current: a DC current that would produce energy at the same rate as the AC source

effective voltage: a DC voltage that would produce energy at the same rate as the AC source

electromagnetic induction: a current is induced to flow in a conductor when that conductor cuts magnetic field lines

electromagnetic radiation: energy carried by electromagnetic waves through space

electromagnetic spectrum: the complete range of electromagnetic waves ordered according to frequency or wavelength

electromagnetic wave: a wave of changing electric and magnetic fields that travels through space

electromotive force: the potential difference across the terminals of a source of electric energy when no current flows to the external circuit

EMF: abbreviation and preferred name for electromotive force

gamma rays: electromagnetic radiation with frequencies of 5×10^{19} Hz or higher that comes from the unstable nuclei of radioactive materials

induced current: a current created through electromagnetic induction

induced EMF: the source of the induced current created by electromagnetic induction

infrared radiation: electromagnetic radiation with a frequency range of about 10^{11} Hz to 10^{14} Hz used mainly for transferring and detecting thermal energy

ionosphere: an upper layer of the atmosphere containing charged particles

Lenz's law: The direction of the induced current is such that it creates a magnetic field that **opposes** the change in magnetic flux that caused the induced current.

magnetic flux: the product of the perpendicular component of the magnetic field and the area of a loop of wire

microwaves: electromagnetic radiation with a frequency range of about 10^{9} Hz to 10^{11} Hz used for cooking, radar, and satellite telecommunication

radio waves: electromagnetic radiation with a frequency range of 100 kHz to 500 MHz used mainly for communications

transformer: a device for increasing or decreasing AC voltage

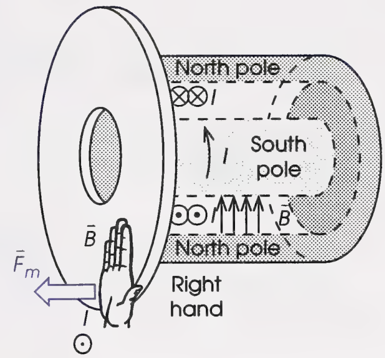
ultraviolet light: electromagnetic radiation with a frequency range of about 8×10^{14} Hz to 3×10^{17} Hz that is responsible for suntanning

visible light: electromagnetic radiation that can be detected by the human eye

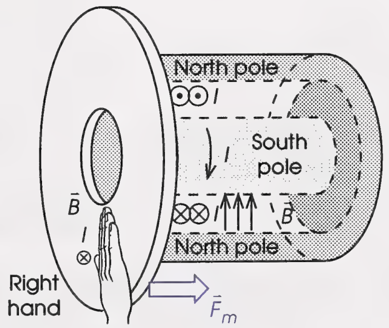
x-rays: electromagnetic radiation with a frequency range of about 3×10^{17} Hz to 5×10^{19} Hz used mainly for medical diagnosis

Suggested Answers

Section 1: Activity 1



1. The diaphragm will be pushed away from the permanent magnet. This is a consequence of the right-hand rule for force applied to the conventional current flowing through the coil that is attached to the diaphragm.



2. The diaphragm will be pulled towards the permanent magnet. This is a consequence of the right-hand rule for force applied to the conventional current flowing through the coil that is attached to the diaphragm.

3. The diaphragm would vibrate back and forth with a frequency of 250 Hz. This would set up sound waves that would have a frequency of 250 Hz.

4. It is more accurate to say that the magnetic coding is rearranged. During recording, the metal on the tape is organized into aligned domains in certain regions. A large external magnetic field would realign those domains, effectively destroying the information.

Section 1: Activity 2

1. An electric current flows through a wire when that wire cuts through magnetic field lines.

2. If the conductor moves parallel to the field lines, it could actually move between two field lines and cut across neither one of them. When the conductor moves perpendicular to the field, it crosses the maximum number of magnetic field lines.

3. The discovery of electromagnetic induction is attributed to Michael Faraday. Joseph Henry made the same discovery in the same year, but Faraday published his work first.

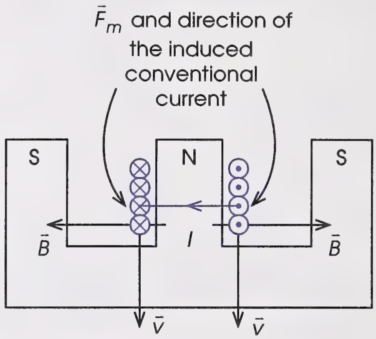
4. The thumb indicates the velocity of the charges. In this case the whole conductor, including the electrons and the imaginary positive charges, has the same velocity. The palm of the hand indicates the direction of the magnetic force on the charges. Since this force causes a current to flow, the palm of the hand also indicates the direction of the induced current. This does not contradict what was presented in Module 5.

5. The equation for induced EMF is $V = B_{\perp} \ell v$.

6. The perpendicular subscript is a good reminder that the magnetic field must be acting perpendicular to the velocity and the direction of induced current flow. This is consistent with the hand rule.

7. According to the hand rule for force, the magnetic force that causes the induced current to flow acts only when the velocity of the conductor is perpendicular to the magnetic field.

8. The right-hand rule for force shows that the induced current will come out of the page on the right side and will go into the page on the left side of the coil. The overall effect is that the induced current will flow clockwise when viewed from the top.



9. The solutions to these problems are on pages 683 and 684 of your textbook.

10. a. To solve this question, it is necessary to first find the speed that the wire possesses as it passes through the magnetic field. You can use kinematic formulas to solve for speed if you are not comfortable with the conservation of energy approach.

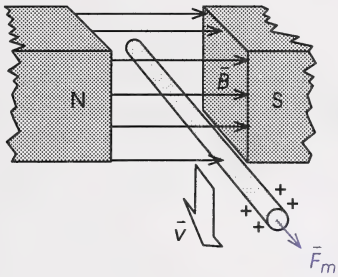
- Find the speed.

$$
\begin{aligned}
\sum E_{before} &= \sum E_{after} \\
E_k + E_p &= E_k{}' + E_p{}' \\
E_p &= E_k{}' \\
mgh &= \frac{1}{2}m(v')^2 \\
v_f{}^2 &= 2\left(9.81\ \text{m/s}^2\right)(3.00\ \text{m}) \\
&= 58.86\ \text{m}^2/\text{s}^2 \\
v_f &= 7.672\ \text{m/s} \\
&= 7.67\ \text{m/s}
\end{aligned}
$$

- Find the induced EMF.

$$
\begin{aligned}
V &= B_{\perp} \ell v \\
&= (1.20\ \text{T})(0.100\ \text{m})(7.672\ \text{m/s}) \\
&= 0.921\ \text{V}
\end{aligned}
$$

b. The right-hand rule for force shows that the imaginary positive charges will be forced to the front of the wire. (This is the same direction as the induced conventional current.) It follows that the front of the wire will become positive, while the back of the wire will become negative.



11. a. generator
    b. microphone
    c. earphones
    d. motor

12. You can use your earphones as a microphone. They have a similar construction, so they will function the same.

    - earphone: An electric current causes a coil to become a magnet moving in an external field. The diaphragm vibrates and produces a sound wave.

    - microphone: A sound wave causes the diaphragm to move. A coil attached to the diaphragm moves in an external field which induces an electric current in the coil.

    You can try this idea yourself. If you have access to a tape recorder or a stereo that has a microphone jack, try using a set of headphones in place of the microphone.

13. The wire is wound around an iron form or core. This allows a great length of wire to interact with the magnetic field.

14. $r = 2.7 \text{ cm}$
    $N = 500 \text{ turns}$
    $\ell = ?$

$$\begin{aligned} \ell &= (\text{circumference}) \times (\text{number of turns}) \\ &= (2\pi r)(N) \\ &= 2\pi(2.70 \text{ cm})(500) \\ &= 8482 \text{ cm} \\ &= 85 \text{ m} \end{aligned}$$

15. When the loop is in the horizontal position, the sides of the loop have a velocity that is entirely perpendicular to the magnetic field lines. In all other positions only a component of this velocity is actually perpendicular to the magnetic field.

16. When the loop is in the vertical position, the sides of the loop have a velocity that is parallel to the magnetic field lines. In this position there is no component of the velocity that is perpendicular to the magnetic field, so the induced current is zero.

17. The current is flowing in different directions in positions 1 and 3. As shown in Figure 25-4(a) on page 519 of the textbook, the induced current is directed into the page at position 1 and out of the page at position 3.

18. It is assumed that the induced EMF is the source of the induced current. According to Ohm's law, changes in the voltage should produce corresponding changes in current. It follows that changes in the induced current were caused by changes in the induced EMF.

19. Motor:

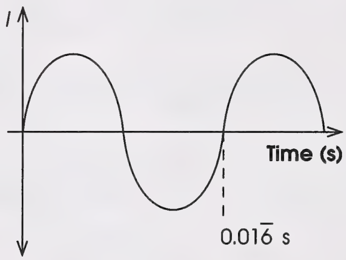
Current flows through the armature. → Due to the presence of a magnetic field, a force is exerted on the armature. → The armature turns.

Generator:

The armature turns. → Due to the presence of a magnetic field, a force is exerted on the charges within the armature windings. → Current flows through the armature.

20. $f = 60\ \text{Hz}$
$T = ?$

$$T = \frac{1}{f} = \frac{1}{(60\ \text{Hz})} = 0.01\overline{6}\ \text{s}$$



As shown on the graph, the period for the AC current is $0.01\overline{6}$ s. This means that the terminal of an AC generator is positively charged for half of that time, or $\frac{0.01\overline{6}\ \text{s}}{2} = 0.008\overline{3}$ s.

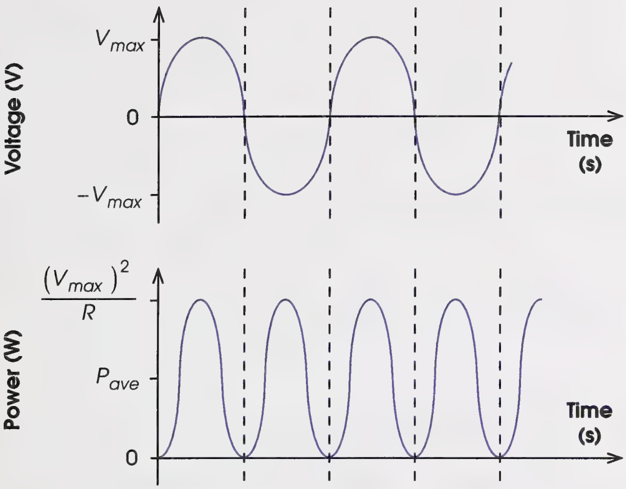
21. The filament remains hot during all parts of the AC current cycle because it does not have enough time to cool down. The bulb therefore remains a continuous source of thermal energy and light and does not flicker.

22. a. Maximum values of instantaneous power are created by maximum positive and maximum negative current values.

b. The instantaneous power values are zero only when the instantaneous current values are zero.

c. The graph for instantaneous power is symmetrical. It varies as a sine wave between a minimum value of zero and a maximum value of $(I_{max})^2 R$. The average of these values will be at the halfway point, or $\frac{1}{2}(I_{max})^2 R$. If the graph was not symmetrical, the halfway point could not be used.

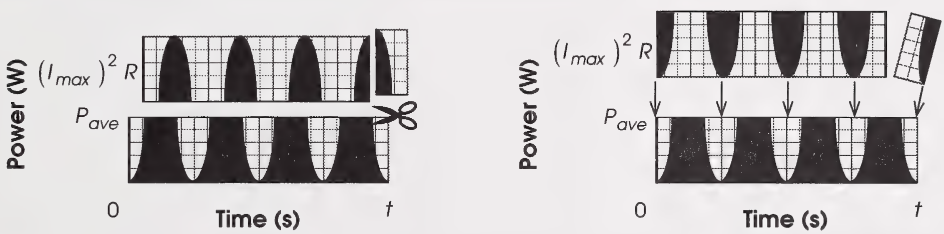
23.



24. Both graphs are symmetrical sine waves. The average, or mean, of both graphs is at the halfway point between the maximum negative and positive amplitudes. In the case of the voltage graph, this means that the average value is zero. In the case of the power graph, the average value is halfway between zero and the maximum value of $\frac{(V_{max})^2}{R}$. This means that the average power must be $\frac{\frac{1}{2}(V_{max})^2}{R}$.

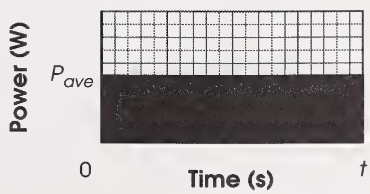
25. The energy would be calculated by multiplying the power by the time. This corresponds to the area under the graph.

26. a. The AC graph would have to be cut horizontally across the line corresponding to P_{ave}. The peaks would then have to be used to fill the valleys, as shown in the following diagrams.



b. The thermal energy produced is calculated by multiplying the average power by the time. This gives the area under the graph.

$$E = P_{ave}t$$
$$= \frac{1}{2}(I_{max})^2 Rt$$



27. The effective value for AC current is equal to the square **root** of the **mean** value **squared**.

28.
$$E_{DC} = E_{AC}$$
$$Pt = P_{ave}t$$
$$\frac{\left(V_{eff}\right)^2 t}{R} = \frac{\frac{1}{2}\left(V_{max}\right)^2 t}{R}$$
$$\left(V_{eff}\right)^2 = \frac{1}{2}\left(V_{max}\right)^2$$
$$V_{eff} = \frac{1}{\sqrt{2}}V_{max}$$
$$V_{eff} = (0.7071)V_{max}$$

29. Textbook question 1.4:

AC current dissipates power in each direction that it flows. Since the equation for power is $P = I^2 R$, the fact that current is squared means that even if the value for current is negative, the corresponding value for power will be positive.

30. These problems are answered on page 684 of your textbook.

Section 1: Activity 3

1. An induced current is forced to flow around the loop when the total number of magnetic field lines through the loop changes.

2. The units of magnetic flux should be magnetic field units (teslas) multiplied by the units for area $\left(\text{metres}^2\right)$.

   This would be written as $\text{T}\bullet\text{m}^2$.

3. $d = 5.2 \text{ cm}$
   $r = 2.6 \text{ cm} = 0.026 \text{ m}$
   $B_\perp = 2.1\times10^{-3} \text{ T}$
   $\Phi_B = ?$

$$\begin{aligned}\Phi_B &= B_\perp A\\ &= B_\perp \pi r^2\\ &= \left(2.1\times10^{-3}\text{ T}\right)(\pi)(0.026\text{ m})^2\\ &= 4.5\times10^{-6}\text{ T}\bullet\text{m}^2\end{aligned}$$

4. $\ell = 6.0 \text{ cm} = 0.060 \text{ m}$
   $w = 2.17 \text{ cm} = 0.0217 \text{ m}$
   $B_\perp = 2.1\times10^{-3} \text{ T}$
   $\Phi_B = ?$

$$\begin{aligned}\Phi_B &= B_\perp A\\ &= B_\perp \ell w\\ &= \left(2.1\times10^{-3}\text{ T}\right)(0.060\text{ m})(0.0217\text{ m})\\ &= 2.7\times10^{-6}\text{ T}\bullet\text{m}^2\end{aligned}$$

5. $\ell = 6.0\ \text{cm} = 0.060\ \text{m}$

$w = 2.17\ \text{cm} = 0.0217\ \text{m}$

$B_{\perp} = 8.5\times10^{-4}\ \text{T}$

$\Phi_B = ?$

$$\begin{aligned}\Phi_B &= B_{\perp}A\\ &= B_{\perp}\ell w\\ &= \left(8.5\times10^{-4}\ \text{T}\right)(0.060\ \text{m})(0.0217\ \text{m})\\ &= 1.1\times10^{-6}\ \text{T}\bullet\text{m}^2\end{aligned}$$

6. The magnetic flux through a loop can be changed by changing the magnetic field strength or the area of the loop.

7. The rotation of the loop causes the area to be reduced relative to the direction of the magnetic field lines. Eventually the loop is parallel to the magnetic field lines and there is no component of the magnetic field perpendicular to the area of the loop.

8. The change in the magnetic flux is the smallest between the times $t = 0$ ms and $t = 1$ ms. During this interval the total number of magnetic field lines is only reduced by one line.

9. Since the magnetic flux made the smallest change in the time interval $t = 0$ ms to $t = 1$ ms, it follows that the induced current should also be smallest during this time interval.

10. Yes, the answers to the previous two questions are consistent with Figures 25-4 and 25-5 on page 519 of the textbook. In both cases the induced current is the weakest when the loop is near the vertical position.

11. The change in the magnetic flux is the largest between the times $t = 2$ ms and $t = 3$ ms. During this interval the total number of magnetic field lines is reduced by three lines.

12. Since the magnetic flux made the largest change between $t = 2$ ms and $t = 3$ ms, it follows that the induced current should also be largest during this time interval.

13. Yes, the answers to the previous two questions are consistent with Figures 25-4 and 25-5 on page 519 of the textbook. In both cases, the induced current is the strongest when the loop is near the horizontal position.

14. time for $\frac{1}{4}$ of a cycle = 3 ms

time for 1 cycle = $T = 12\ \text{ms} = 1.2\times10^{-2}\ \text{s}$

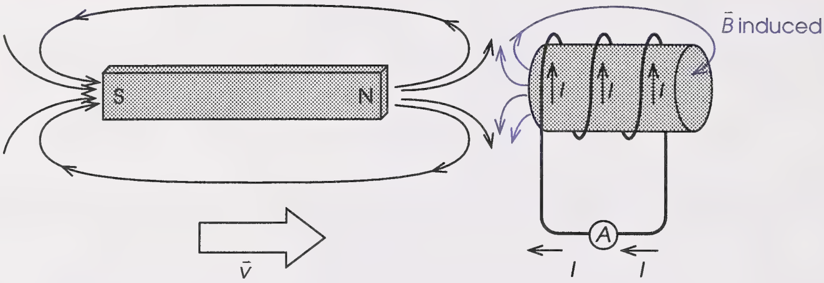
$f = ?$

$$\begin{aligned}f &= \frac{1}{T}\\ &= \frac{1}{1.2\times10^{-2}\ \text{s}}\\ &= 83\ \text{Hz}\end{aligned}$$

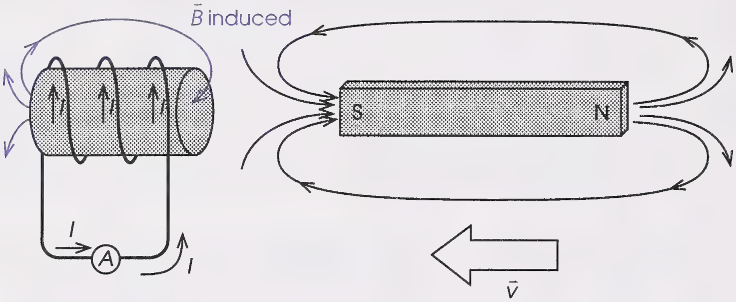
The frequency of the loop in this generator is 83 Hz, so the frequency of the induced AC current must also be 83 Hz.

15. The direction of the induced current is such that the magnetic field lines generated by this current will oppose the change in flux that caused this induced current in the first place.

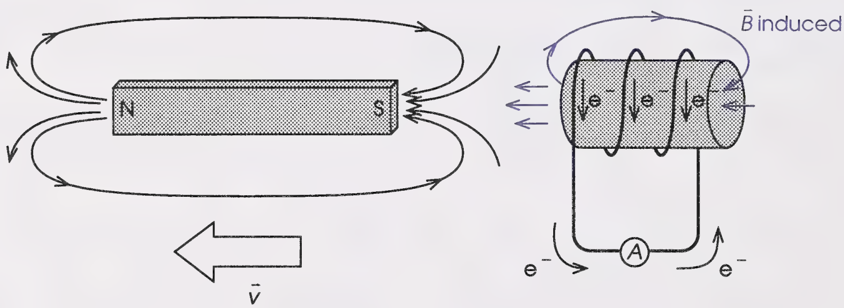
16. a.



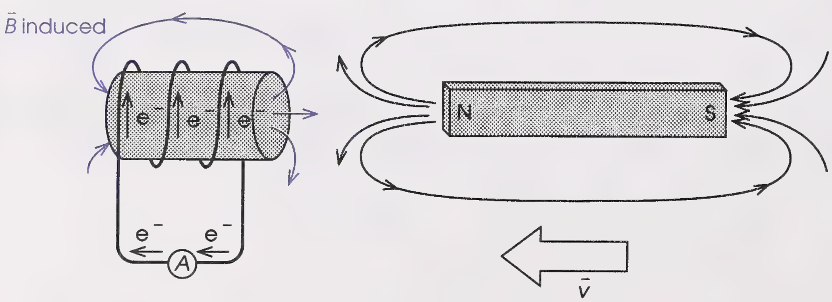
b.



17. a. Remember to use the left-hand rule for coils here.



b. Use the left-hand rule for coils here as well.

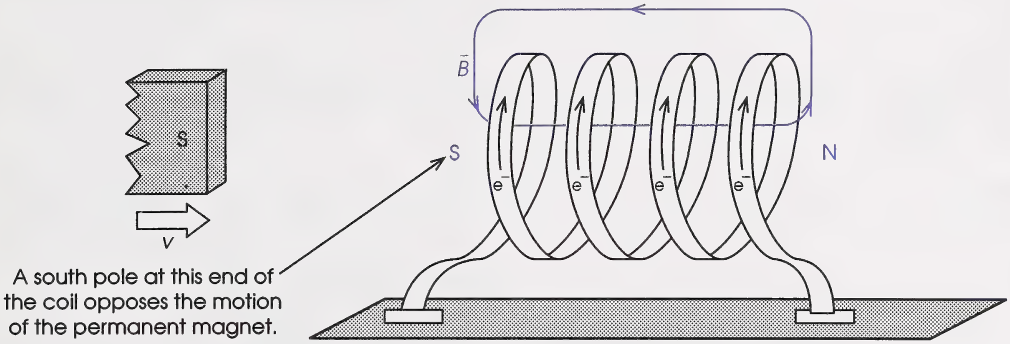


18. a. battery
    b. primary coil
    c. iron ring
    d. secondary coil
    e. galvanometer

19. The device shown in question 18 is called a transformer.

20. An induced magnetic field always opposes the change in the magnetic field that creates that induced field.

21. Remember to use the induced electron current for this question.



22. a. The diagram represents a simple electric generator.

    b. The device between the poles of the magnet is called the armature.

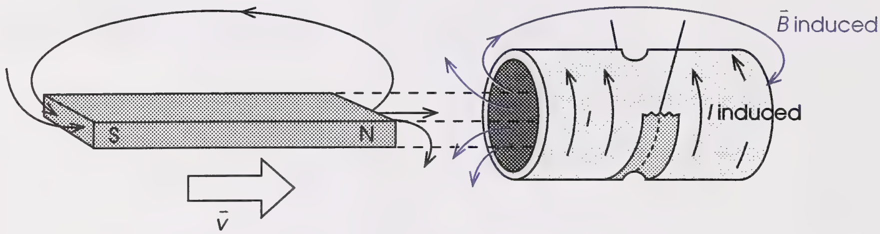
    c. An alternating current is induced in the wire leads as the armature rotates. As the armature turns, it moves through an external magnetic field to generate an induced electron flow and an induced magnetic field. According to Lenz's law, an induced magnetic field will appear so that it opposes the motion which creates it, so as the armature rotates from one magnetic pole to the next, its induced magnetic field must switch directions. This results in a switch in the direction of the electron flow within the coils of the armature.

23. Since copper is not a ferromagnetic material, the coupling should not be attracted to the magnet. This is verified by the fact that the magnet will not attract the coupling.

24. No, the coupling does not swing when the bar magnet is substituted with a nonmagnetic object.

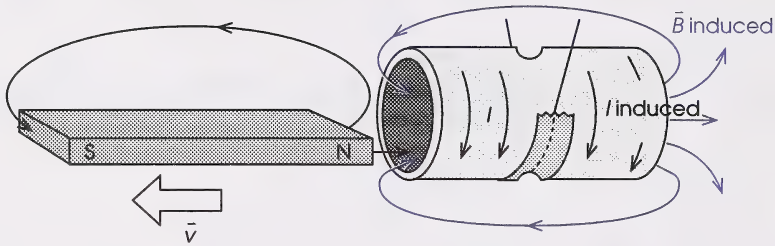
25. The coupling must have currents induced in it that allow it to interact with the bar magnet. This is in accordance with Lenz's law.

26. This question is answered using the right-hand rule for coils to show the direction of the induced conventional current.



As the north pole of the magnet is pushed into the coil, the induced magnetic field of the coupling opposes this change in flux and is repelled by the north end of the magnet. The coupling ends up moving to the right with the magnet.

When the magnet is withdrawn, the process reverses.



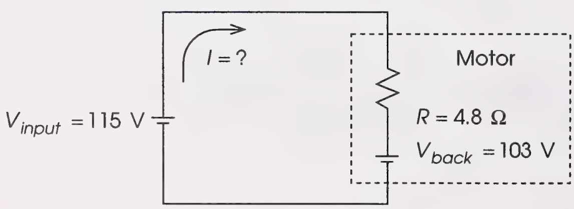
In this case the induced magnetic field of the coupling opposes this change in flux and is attracted to the north end of the magnet. The coupling ends up moving to the left with the magnet.

27. Resonance occurs when the driving force of a system is applied at a frequency that matches the natural frequency of vibration of the system. In this investigation the driving force was the motion of the bar magnet that matched the natural frequency of the coupling pendulum.

28. The swinging of the coupling could not be due to air currents caused by the motion of the hand because if this was the case, then the nonmagnetic object should have produced the same effect. Clearly it is important for the magnet to be moving, which implies a Lenz law effect.

Section 1: Activity 4

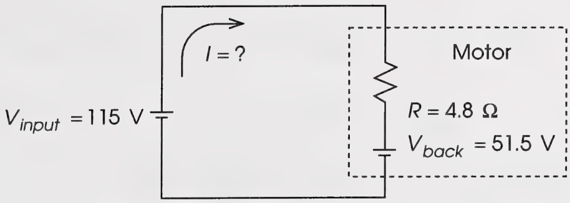
1. a.



Kirchhoff's loop rule can be applied to this circuit.

$$
\begin{aligned}
V_{input} - V_{resistance} - V_{back} &= 0 \\
V_{input} - IR - V_{back} &= 0 \\
IR &= V_{input} - V_{back} \\
I &= \frac{V_{input} - V_{back}}{R} \\
&= \frac{(115\ \text{V}) - (103\ \text{V})}{4.8\ \Omega} \\
&= \frac{12\ \text{V}}{4.8\ \Omega} \\
&= 2.5\ \text{A}
\end{aligned}
$$

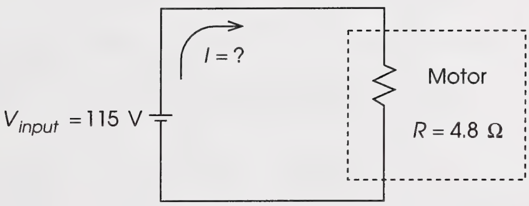
b. Since the motor is turning half as fast, the back-EMF is only half as much: $\frac{103\ \text{V}}{2} = 51.5\ \text{V}$.



- Kirchoff's loop rule:

$$V_{input} - V_{resistance} - V_{back} = 0$$
$$V_{input} - IR - V_{back} = 0$$
$$\begin{aligned} I &= \frac{V_{input} - V_{back}}{R} \\ &= \frac{(115\ \text{V}) - (51.5\ \text{V})}{4.8\ \Omega} \\ &= \frac{63.5\ \text{V}}{4.8\ \Omega} \\ &= 13\ \text{A} \end{aligned}$$

c. When the motor stops, there is no induced EMF. In this case the motor acts simply as a resistance.



- Ohm's law:

$$V_{input} = IR$$
$$\begin{aligned} I &= \frac{V_{input}}{R} \\ &= \frac{115\ \text{V}}{4.8\ \Omega} \\ &= 24\ \text{A} \end{aligned}$$

2. If the load connected to a motor is increased, the motor is doing more work. By the law of conservation of energy, if the motor is doing more work, it would require more energy to sustain its operation. The increase in the current that is drawn corresponds to the increased demand for energy by the motor.

3. For the motor to have full input voltage and yet no back-EMF, the armature must not be turning. This occurs the instant the motor is just starting and when the motor is forced to stop when it is overloaded.

4. In both of these circumstances, the armature is not turning and so there is no back-EMF to counter the input voltage and lower the current. Most motors are designed to handle a range of current values that corresponds to normal operation. The high current associated with starting lasts for only a fraction of a second and is part of normal operation. However, when the motor stops due to overloading, the high current can last indefinitely or until the associated heating effects melt the wires and burn out the motor.

5. When the machine is first switched on, there is an instant when there is no back-EMF and the current is very large. This large current causes voltage drops around other devices connected in parallel on the same circuit. If these devices are lights, they will tend to dim.

6. Self-inductance occurs when the current and the magnetic flux through a coil change. This change in magnetic flux creates an induced EMF and an induced current within the coil that acts to oppose this change. All of this is in accordance with Lenz's law. Although this situation is very similar to back-EMF within a motor, this case has an added dimension. A coil will naturally tend to resist any change in the current that it carries, just as a mass naturally tends to resist any change in its motion.

7. The car naturally tends to resist changes in its motion. This is known as the law of inertia. In a similar way, a coil will naturally tend to resist changes in the current that it carries. This is known as self-inductance and is in accordance with Lenz's law.

8. a. The display would change polarity, switching from positive to negative or negative to positive.

   b. When using the 800-turn solenoid, the induced current flow is larger than if you used the 400-turn solenoid. The exact values depend on the speed at which you moved the magnet, so they will vary.

9. The bar magnet produces a stronger magnetic field. According to domain theory, a magnet has more aligned magnetic domains than an unmagnetized piece of steel.

10. You should notice a definite difference. The bar magnet should give values at least 40 μA greater than the steel bolt. A greater induced current must be due to a bigger magnetic field (more aligned domains) if everything else is kept constant.

11. When the power supply was detached from the solenoid, a tiny current momentarily surged through the other solenoid and was measured by the multimeter. When the power supply was reattached, a tiny current again momentarily surged through the other solenoid, but this time it was in the other direction.

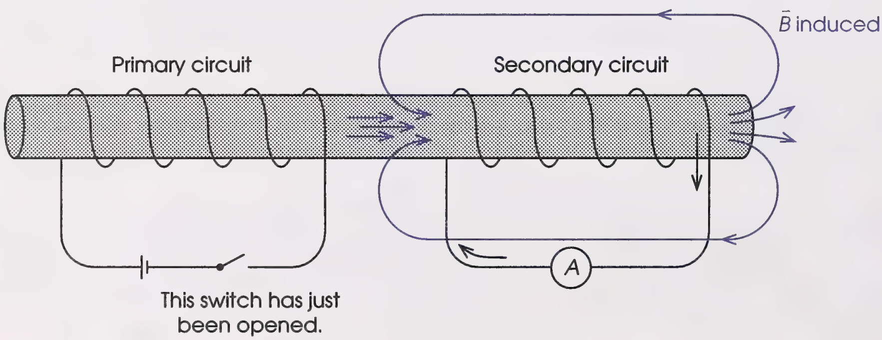
12. The 9-V setting simply intensified the results and made the induced current in the secondary coil stronger. The observation should still be made that detaching the power supply causes a tiny current to momentarily surge in one direction, while reattaching the power supply causes a tiny current to momentarily surge in the other direction.

13. Connecting the solenoid in the primary circuit causes the magnetic flux to increase. Disconnecting the solenoid in the secondary circuit causes the magnetic flux to decrease.

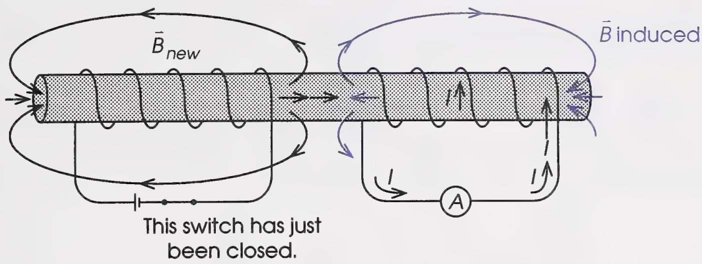
14. The steel bolt increases the magnetic field strength created by the solenoids because the domains of the iron atoms in the steel align with the magnetic field lines.

15. The 400-turn solenoid is not connected to the primary circuit, but it is influenced by the changing magnetic flux created by the primary coil. According to Lenz's law, this changing magnetic flux induces a current in the secondary coil that opposes this original change in magnetic flux.

16. a. In this case the induced magnetic field in the secondary coil acts to maintain the initial magnetic field in the primary coil. In other words, the magnetic field is acting to oppose the collapse of the original field created by the primary coil. Using the right-hand rule for coils, the induced conventional current in the secondary coil can be determined as shown in the following diagram.



b. Closing the switch causes a new magnetic field to be created in the primary coil. This is a change in flux, as indicated by the direction of $\vec{B}_{new}$ on the following diagram. In response to this, a magnetic field is induced in the secondary coil to oppose this change. The direction of the induced current flow can then be determined for the secondary coil using the right-hand rule for coils.



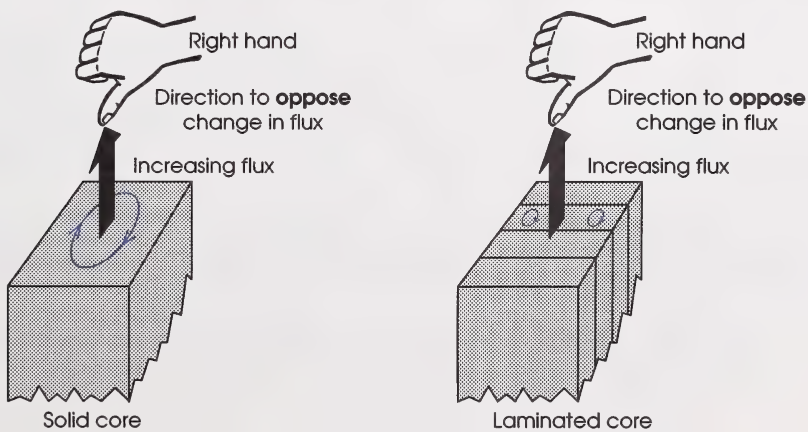
17. The primary coil is always the one which is connected to an external power source. This means that coil A is the primary coil and coil B is the secondary coil.

18. A step-up transformer is one that has a higher secondary voltage than primary voltage. In other words, it takes the primary (input) voltage and steps it up to a higher value. The reverse applies to a step-down transformer.

19. The second equation comes from the assumption that the power (rate of using electric energy) consumed by the primary coil is equal to that provided to the secondary coil. This stems from the equation $P = IV$. Since the rate of using energy is the same in both coils, both coils would use the same amount of energy in the same amount of time. This is in accordance with the law of conservation of energy.

20. If the secondary coil was provided all of the energy available to it from the primary coil, no energy was lost in the transfer. This is an idealized situation because all transformers produce small amounts of thermal energy, which means that not all of the input energy from the primary coil shows up as useful energy in the secondary coil.

21. As shown in the following diagram, the fingers of the right hand will indicate the direction of the induced conventional current.



22. The thin sheets are used to reduce the size of the eddy currents. If the sheets were not coated, the currents could continue to flow between the sheets. The insulated coating forces the eddy currents to be contained within each individual sheet.

23. The answers to these problems can be found on page 684 of your textbook.

24. High voltages are used in long-distance transmission of electric energy mainly for efficiency reasons. Current flow through the wires leads to heating of the wires and the heat energy is radiated into space. This results in a loss of energy between transmission and reception. Increasing the voltage of transmission allows the same power to be transmitted with less current flow.

25. a. A step-down transformer lowers the voltage before it enters your home. This transformer consists of a secondary coil with fewer turns than the primary coil.

    b. The ideal transformer equation states $\frac{V_p}{V_s}=\frac{N_p}{N_s}=\frac{I_s}{I_p}$, so $V_s=\frac{(V_p)(N_s)}{N_p}$.

26. Textbook question 13. a.:

$$(0.85)P_{total} = 375\times10^6\ \text{W}$$
$$P_{total} = \frac{375\times10^6\ \text{W}}{0.85} = 4.41\times10^8\ \text{W}$$

Textbook question 13. b.:

$$P=\frac{E}{t}$$
$$E = Pt = \left(4.41\times10^8\ \text{J/s}\right)(1.0\ \text{s}) = 4.41\times10^8\ \text{J}$$

Textbook question 13. c.:

$$E = mgh$$
$$m=\frac{E}{gh} = \frac{\left(4.41\times10^8\ \text{J}\right)}{\left(9.81\ \text{m/s}^2\right)(22\ \text{m})} = 2.0\times10^6\ \text{kg}$$

Textbook question 17. a.:

$$V_p = 1.2\ \text{kV}$$
$$V_s = 240\ \text{kV}$$
$$\frac{N_p}{N_s} = ?$$

$$\frac{N_p}{N_s}=\frac{V_p}{V_s} = \frac{1.2\ \text{kV}}{240\ \text{kV}} = \frac{1}{200}$$

The ratio of the number of turns on the primary to the number of turns on the secondary is $1:200$.

Textbook question 17. b.:

$$I_p = 40.0\ \text{A}$$
$$I_s = ?$$
$$V_p = 1.2\ \text{kV}$$
$$V_s = 240\ \text{kV}$$

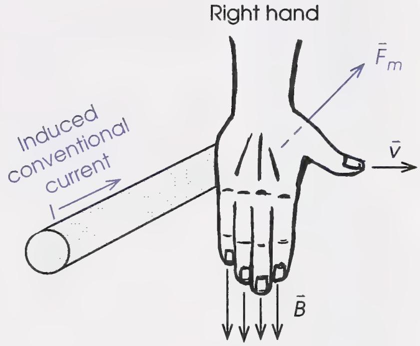
$$\frac{V_p}{V_s}=\frac{I_s}{I_p}$$
$$I_s = \frac{V_p I_p}{V_s} = \frac{(1.2\ \text{kV})(40.0\ \text{A})}{240\ \text{kV}} = 0.20\ \text{A}$$

27. a. UHV transmission lines are electric transmission lines designed to carry voltages at 2000 kV, which is much greater than the present 765 kV.

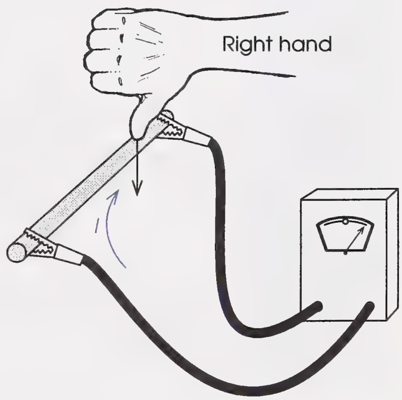
    b. The demand for electric power by the consumer has doubled in recent years and, in order to keep up with the demand, greater amounts of power at the same efficiency must be transmitted.

Section 1: Follow-up Activities

Extra Help



1. a. When the right-hand rule for force is applied to the wire, the conventional current is found to flow from front to back, as shown in the diagram.



b. As the loop is pulled to the right, the total number of magnetic field lines within the loop will decrease. According to Lenz's law, a current will be induced to flow in the loop that will oppose this change. In other words, the induced current will flow to create more downward magnetic field lines. This means that the induced conventional current will flow from front to back through the straight wire.

c. No, there is no difference in the answers. Both methods predict the same direction for the induced current.

d. No, it is not possible for the magnetic flux through the loop to change without the loop cutting magnetic field lines. For the magnetic flux to decrease by pulling the loop to the right, the loop must cut through the field lines that exist between the poles of the magnets. If the loop is to be pushed back to its original position, increasing the magnetic flux through the loop, the loop must again cut across the magnetic field lines between the magnets.

e. The two approaches simply provide different points of view for applying the same concept. When working with straight conductors, one approach is more convenient, while the other method is best suited to loops and coils. When used properly, both approaches will yield the same answer.

2.

Term	Definition	Symbol	Units	Equation
Induced EMF	source of the induced current created by electromagnetic induction	V	volts	$V = B_{\perp}\ell v$
Effective Current	a DC current that would produce thermal energy at the same rate as the AC source	I_{eff}	amperes	$I_{eff} = \frac{1}{\sqrt{2}} I_{max} = (0.7071) I_{max}$
Effective Voltage	a DC voltage that would produce thermal energy at the same rate as the AC source	V_{eff}	volts	$V_{eff} = \frac{1}{\sqrt{2}} V_{max} = (0.7071) V_{max}$
Magnetic Flux	the product of the perpendicular component of the magnetic field and the area of a loop of wire	Φ_B	telsas • metres^2	$\Phi_B = B_{\perp} A$
Back-EMF	the induced EMF in a motor which acts to oppose the motion of the motor	V_{back}	volts	$V_{back} = V_{input} - IR$ (R is the motor's resistance.)
Secondary Voltage	the induced EMF in the secondary coil of a transformer	V_s	volts	$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$

Enrichment

1. You can check your answers in the solutions part of the *Enrichment* booklet.

2. a. Transformers contain transformer oil that can be toxic. When taking apart a transformer, it is almost impossible to not come in contract with the oil. It is also necessary to store the oil properly, something that you are probably not equipped to do.

   b. Transformers appear anywhere a voltage or current is stepped up or down. Some of the devices you may have listed are battery rechargers, ignition coils in automobiles, or television picture tubes. The one transformer which plays the most important role in your life is one you may take for granted. It is the box somewhere close to your house that steps down the voltage carried over the power transmission lines from hundreds of thousands of volts to 110 or 220 V for your home use.

Section 2: Activity 1

1. When the motor is off there is no interference with the radio signal, so the motor must be responsible.

2. A motor consists of a coil of wire wound around a metal rod to form the armature. Current is made to flow through the coil. This is similar to your solenoids.

3. A clicking sound is heard whenever the current flow is interrupted.

4. The clicking sound is very difficult to detect when the solenoid is not part of the circuit.

5. It was the changing magnetic flux from the primary coil that induced the current in the secondary coil.

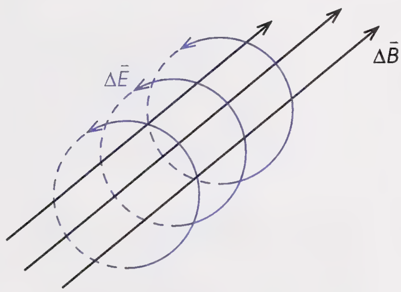
6. The changing magnetic field lines from the solenoid somehow enabled the solenoid to influence the radio.

7. No, there is no iron or steel core that links both the solenoid and the radio.

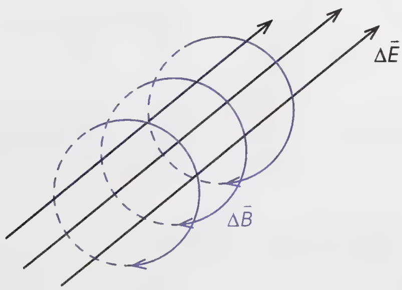
8. Following the line of thought suggested by the previous questions, it would appear that radio waves somehow include changing magnetic fields.

9. James Maxwell first predicted the existence of electromagnetic waves.

10. A changing magnetic field produces a changing electric field, as shown in the diagram. Unlike the static electric fields studied earlier, these electric field lines form closed loops. See the note after the following question.

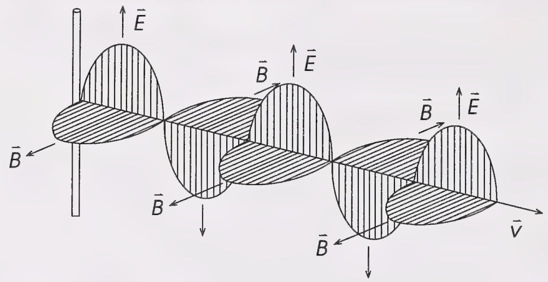


11. A changing electric field produces a changing magnetic field, as shown in the diagram.



Note: The direction of the circular magnetic field in this case is opposite to the direction of the circular electric field in the previous question. Although the full explanation as to why these directions are opposite goes beyond the scope of the Physics 30 course, it is interesting to note the symmetry.

12. An electromagnetic wave propagates through space by the changing electric field creating a changing magnetic field, which in turn creates a changing electric field, and so on.



As shown in the diagram, these fields act perpendicularly to each other and to the direction of the wave velocity. Note that in this example the electric fields are in the vertical plane, while the magnetic fields are in the horizontal plane.

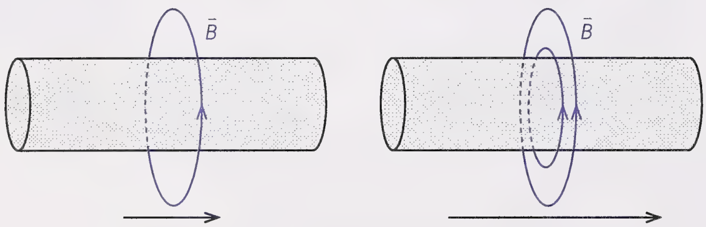
13. Electromagnetic waves are all initiated by accelerating charges. Note that accelerating charges can also account for changing magnetic fields as proposed by Maxwell.

14. Maxwell calculated the speed of propagation for electromagnetic waves in a vacuum and he calculated it to be 3.00×10^{8} m/s. Since this value is the speed of light, it suggests that light itself may be an electromagnetic wave.

Section 2: Activity 2

1. If two polarizing filters are crossed at 90° in their planes of alignment, no light will get through both filters. Blackness should result.

2.

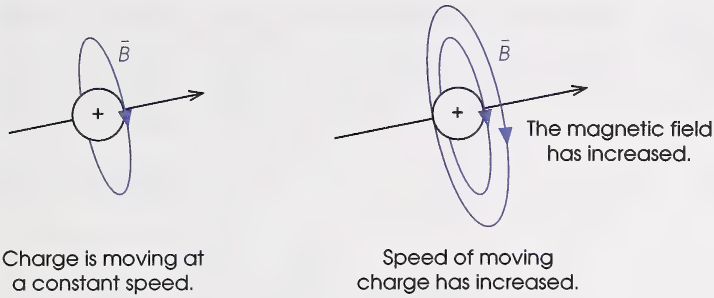


Electron flow is small

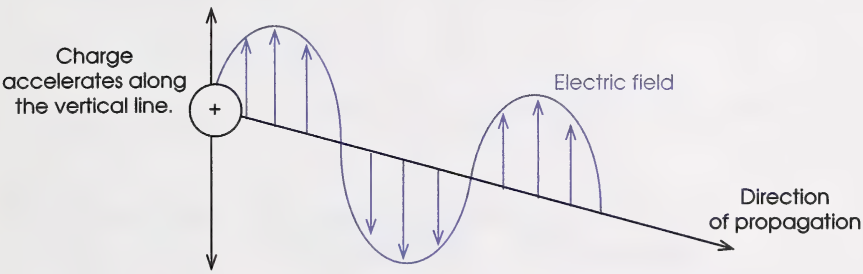
Electron flow is increased

3. A changing magnetic field would create a changing electric field, which could cause a current to flow.

4.



5.



6. a. transformer
   b. terminals

7. The transformer acts to step up the voltage, and the terminals allow a spark to oscillate in the space between them.

8. Hertz used a wire loop with a gap in it to act as a detector. Sparking at the gap indicated reception of an electromagnetic wave.

9. The list of wavelengths from longest to shortest follows: radio waves, microwaves, infrared radiation, visible light, ultraviolet light, x-rays, and gamma rays.

10. a. Red light

$f = 4.8 \times 10^{14}$ Hz

$c = 3.00 \times 10^{8}$ m/s

$\lambda = ?$

$$c = f\lambda$$

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^{8}\ \text{m/s}}{4.8 \times 10^{14}\ \text{Hz}} = 6.3 \times 10^{-7}\ \text{m}$$

AM Radio Waves

$f = 740\ \text{kHz} = 740 \times 10^{3}$ Hz

$c = 3.00 \times 10^{8}$ m/s

$\lambda = ?$

$$c = f\lambda$$

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^{8}\ \text{m/s}}{740 \times 10^{3}\ \text{Hz}} = 405\ \text{m}$$

b. The wavelength of red light is much smaller than the wavelength of police radar, while the wavelength of AM radio waves is much longer.

c. The red light from the police laser has a much smaller wavelength than the radar that the detector is designed to receive.

11. a. $f = 4.78 \times 10^{14}\ \text{Hz}$

$v_{air} = 3.00 \times 10^{8}\ \text{m/s}$

$v_{water} = 2.256 \times 10^{8}\ \text{m/s}$

$\lambda_{air} = ?$

$\lambda_{water} = ?$

$$v = f\lambda$$

$$\lambda_{air} = \frac{v_{air}}{f} = \frac{3.00 \times 10^{8}\ \text{m/s}}{4.78 \times 10^{14}\ \text{Hz}} = 6.28 \times 10^{-7}\ \text{m}$$

$$v = f\lambda$$

$$\lambda_{water} = \frac{v_{water}}{f} = \frac{2.256 \times 10^{8}\ \text{m/s}}{4.78 \times 10^{14}\ \text{Hz}} = 4.72 \times 10^{-7}\ \text{m}$$

Note that v_{air} could have been replaced with c, but v_{water} could not have been replaced with c since the speed is not $3.00 \times 10^{8}\ \text{m/s}$.

b. The frequency of the red light is the same in both media. The frequency of a wave depends on the source, not the medium.

c. The frequency of a type of electromagnetic wave will not change with the medium. The wavelength will change.

d. When the universal wave equation is written in this way, it reminds the student that the wavelength depends on both the medium and the frequency of the source.

$$\boxed{\lambda = \frac{v}{f}}$$

Depends on the medium
Depends on the source

Depends on both the medium and the source

12. Textbook question 7. a.:

Radio waves have the longest wavelength.

Textbook question 7. b.:

X-rays have the highest frequency.

Textbook question 7. c.:

All three waves will have the same velocity in a vacuum: $3.00 \times 10^{8}\ \text{m/s}$.

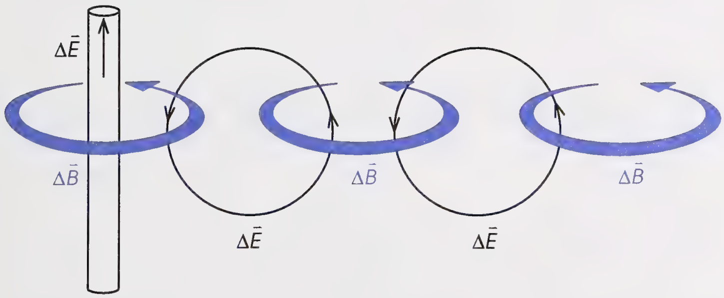
13. The similarities between mechanical waves and electromagnetic waves have to do with the fact that both types of waves transfer energy and that both types of waves can be described by the variables of the universal wave equation. The major difference is that mechanical waves require a medium to do the vibrating and carry the wave's energy. Electromagnetic waves do not require a medium because it is the oscillating fields that carry the energy.

Section 2: Activity 3

1. Textbook question 5:

An AC generator must be used to create electromagnetic waves because an electromagnetic wave consists of changing electric and magnetic fields. If a DC generator was used, the fields would only be created when the generator is switched off and on, since this is the only time that the charges would change velocity.

Textbook question 6:



2. $f_1 = 88\ \text{MHz} = 88 \times 10^6\ \text{Hz}$

$f_2 = 108\ \text{MHz} = 108 \times 10^6\ \text{Hz}$

$c = 3.00 \times 10^8\ \text{m/s}$

$\lambda_1 = ?$

$\lambda_2 = ?$

$$\begin{aligned} c &= f\lambda \\ \lambda_1 &= \frac{c}{f_1} \\ &= \frac{3.00 \times 10^8\ \text{m/s}}{88 \times 10^6\ \text{Hz}} \\ &= 3.4\ \text{m} \end{aligned}$$

$$\begin{aligned} c &= f\lambda \\ \lambda_2 &= \frac{c}{f_2} \\ &= \frac{3.00 \times 10^8\ \text{m/s}}{108 \times 10^6\ \text{Hz}} \\ &= 2.8\ \text{m} \end{aligned}$$

3. Waves will scatter best if the size of the object is the same size or larger than the wavelength of the wave. Aircraft have parts that are about the same size or slightly larger than the wavelength of TV waves, so aircraft can scatter these waves. AM radio waves are much larger than most aircraft, so in this case little scattering will occur as the wave diffracts around the plane.

4. Waves will diffract around an object if that object is about the same size as the wavelength of the wave or smaller. Since AM radio waves are larger than most buildings they can diffract around them. FM radio waves are unable to do this because their wavelength is too short so they create shadows behind the buildings.

5. Textbook question 2.2:

Since the television rods are horizontal, the electric fields in the television signal must also be horizontal.

Textbook question 2.3:

The longer antenna would be required by channel 6 since it has the longer wavelength.

6. Textbook question 8:

If the car radio antennae are vertical, the electric fields in the radio signal that they are designed to detect must also be vertical.

Textbook question 9:

The antenna reception circuitry is tuned to receive only one wavelength. This is accomplished by the capacitor and coil in the circuit being adjusted to a resonant frequency.

7. $f = 2.45 \times 10^{9}\ \text{Hz}$

$c = 3.00 \times 10^{8}\ \text{m/s}$

$\lambda = ?$

$$c = f\lambda$$
$$\lambda = \frac{c}{f}$$
$$= \frac{3.00 \times 10^{8}\ \text{m/s}}{2.45 \times 10^{9}\ \text{Hz}}$$
$$= 0.122\ \text{m}$$
$$= 12.2\ \text{cm}$$

8. Textbook question 4:

The metal pan will reflect the microwaves, whereas the ceramic mug will allow the microwaves to pass through to the water. The handle of the mug will not get as hot because it is not adjacent to water molecules. The microwaves are tuned to the natural frequency of water molecules.

9. Textbook question 9:

Our eyes are about 1 cm in size, which is 100 000 times larger than the wavelength of the light waves they are designed to detect. Since microwaves have wavelengths about 10 cm long, the eyes should be 100 000 times larger, or about 10 km in size.

10. When people are lost at sea or in dense bush, their own infrared emissions may be the only source of heat in such harsh environments. This would help rescuers identify them from search aircraft (even at night) using specialized infrared detectors.

11. $f_1 = 1 \times 10^{11}\ \text{Hz}$

$f_2 = 1 \times 10^{14}\ \text{Hz}$

$c = 3.00 \times 10^{8}\ \text{m/s}$

$\lambda_1 = ?$

$\lambda_2 = ?$

$$c = f\lambda$$
$$\lambda_1 = \frac{c}{f_1}$$
$$= \frac{3.00 \times 10^{8}\ \text{m/s}}{1 \times 10^{11}\ \text{Hz}}$$
$$= 3 \times 10^{-3}\ \text{m}$$

$$c = f\lambda$$
$$\lambda_2 = \frac{c}{f_2}$$
$$= \frac{3.00 \times 10^{8}\ \text{m/s}}{1 \times 10^{14}\ \text{Hz}}$$
$$= 3 \times 10^{-6}\ \text{m}$$

12. Textbook question 3:

    Responses will vary. You should mention that reducing the emission levels for CO_2 and other greenhouse gases would be prudent until the workings of the atmosphere and the nature of the problem are understood better.

13. The name Roy G Biv stands for the colours of the spectrum: red, orange, yellow, green, blue, indigo, and violet.

14. The principle is that light travels to your eyes in straight lines. You assume this to be true because when you see things, you trace the light back on a straight line to its source.

15. White light is composed of all the colours in the visible spectrum.

16. Unlike a phonograph record, there is no contact on the surface of a compact disc by an object with mass. The laser beam is the only thing to contact the disc, but this does not wear the disc out.

17. A colour television set utilizes additive colour theory.

18. A dye is a molecule that absorbs certain colours of light, and transmits or reflects others. A pigment particle behaves similarly to a dye but it is larger than a molecule.

19. Textbook question 2.4:

    A hole in the ozone layer could mean that the whole layer is starting to deteriorate. If this was true, harmful ultraviolet radiation could reach Earth's surface. For human beings the first immediate consequence could be an increase in the rate of skin cancer.

20. Although answers will vary to this question, they will likely centre around one main point. A suntan is actually a fashion statement that reflects current ideas about beauty in our culture. In the winter time, a tan can be a status symbol because it immediately tells people that you can afford to go to warmer climates. It is interesting to know that many people who grew up in the 1940s and 1950s are now suffering from cancers and other illnesses that stem from the then fashionable trend of cigarette smoking. Now cigarette smoking is recognized as the leading cause of cancers rather than a sign of worldly sophistication. Doctors and cancer researchers are now estimating what the incidence of skin cancers will be from society's current preoccupation with fashionable suntans.

21. Long-term exposure to the sun has been linked to skin cancers, premature aging of the skin, and brown, blotchy marks on the skin.

22. A deep suntan has the short-term benefit of helping a person fit into the current trends in body image and fashion. However the long-term consequences mentioned in the previous question seem to make the risks much larger than the benefits. It's curious that even from the point of view of personal appearance and beauty, a tan that lasts a few weeks could help contribute to years of early wringles and leathery skin. It seems to be a poor trade.

23. X-rays are produced when electrons with high kinetic energy are rapidly decelerated upon striking a metal surface. The kinetic energy from the electrons is transferred to the creation of an x-ray.

24. A TV uses an electron beam to produce a picture on the phosphor coated screen. The deceleration of the electrons against the glass can produce x-rays. The lead in the glass screen is to help shield the viewers from any stray x-rays.

25. The fact that this procedure is nonsurgical and that it can be done relatively quickly means that there is less trauma to the patient.

26. Fetuses and infants are in a stage of rapid growth and development. Since this implies a very high rate of cell division, they are very vulnerable to the effects of ionizing radiation.

27. As explained in the answer to the previous question, the unborn baby is very vulnerable to x-ray radiation.

28. All of the waves in the electromagnetic spectrum are types of electromagnetic radiation. Visible light is a form of radiation that is the basis for all life on the planet. Without photosynthesis, life could not exist as you know it. When you sit close to a friend and feel the warmth of their body, you are really detecting the infrared radiation of their body. Listening to an FM radio station requires you and your radio to be surrounded by the radiations from the radio station's antenna. Clearly the word *radiation* applies to a wide variety of phenomena, most of which are either essential or desired in everyday living.

29. If the cancer cells are growing rapidly, they are dividing frequently and replicating their DNA. This makes them vulnerable to ionizing radiation. A carefully directed beam of gamma radiation could be used to damage and kill the cancer cells.

Section 2: Follow-up Activities

Extra Help

The following chart shows representative answers. There are other possible correct responses. Note that the wavelengths have been rounded off in some cases because they were calculated from the stated frequency using $c = f\lambda$.

	Radio Waves	Micro-waves	Infrared Radiation	Visible Light	Ultraviolet Light	X-rays	Gamma Rays
Range of Wavelengths in Air (m)	3000 to 0.6	0.6 to 0.003	0.003 to 8×10^{-7} m	7×10^{-7} to 4×10^{-7}	4×10^{-7} to 1×10^{-9}	1×10^{-9} to 6×10^{-12}	6×10^{-12} and higher
Sources	oscillating electrons in a broadcast antenna	charges accelerating in resonant cavities	molecular vibrations	energy transitions within atoms	high-energy transitions within atoms	decelerating electrons strike metal surface	unstable nuclei of radioactive materials

	Radio Waves	Micro-waves	Infrared Radiation	Visible Light	Ultraviolet Light	X-rays	Gamma Rays
Possible Detectors	electrons in a receiving antenna	electrons within molecules	molecules	electrons within atoms	electrons within atoms	electrons within atoms	electrons within atoms
Applications	communi-cations	cooking, radar, satellite communi-cations	identifying heat loss in buildings, search and rescue	lasers (compact discs), vision	tanning	medical diagnosis and procedures	cancer treatment

Enrichment

1. The answer to this activity can be found in the answer key of the *Enrichment* booklet.

2. a. ELF radiation is the extremely low frequency EMR given off by AC currents in many household appliances.

   b. ELF radiation was originally not thought to be hazardous to tissue cells because the electric fields normally inside cells are so much larger than ELF electric fields that it was thought that you could ignore ELF radiation.

   c. ELF radiation has been found to have the following effects on tissue cells:

   - affect flow of ions across cell membranes
   - affect the synthesis of DNA
   - affect the response of cells to hormones

   d. There is no clear consensus on the danger of ELF radiation because there is no clear way to define or measure the dosage of ELF radiation received.

   e. The evidence that has shown ELF radiation to be a possible environmental hazard consists primarily of small increases in the incidence of leukemia and breast and brain cancers.

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Physics 30

Student Module Booklet
Module 6

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